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July 1999

Monitoring Completed Navigation Projects Program

Periodic Inspection of Jetties at Manasquan Inlet, New Jersey

Armor Unit Monitoring for Period 1994-1998

by Robert R. Bottin, Jr., WES
William F. Rothert, Philadelphia District

Prepared for Headquarters, U.S. Army Corps of Engineers

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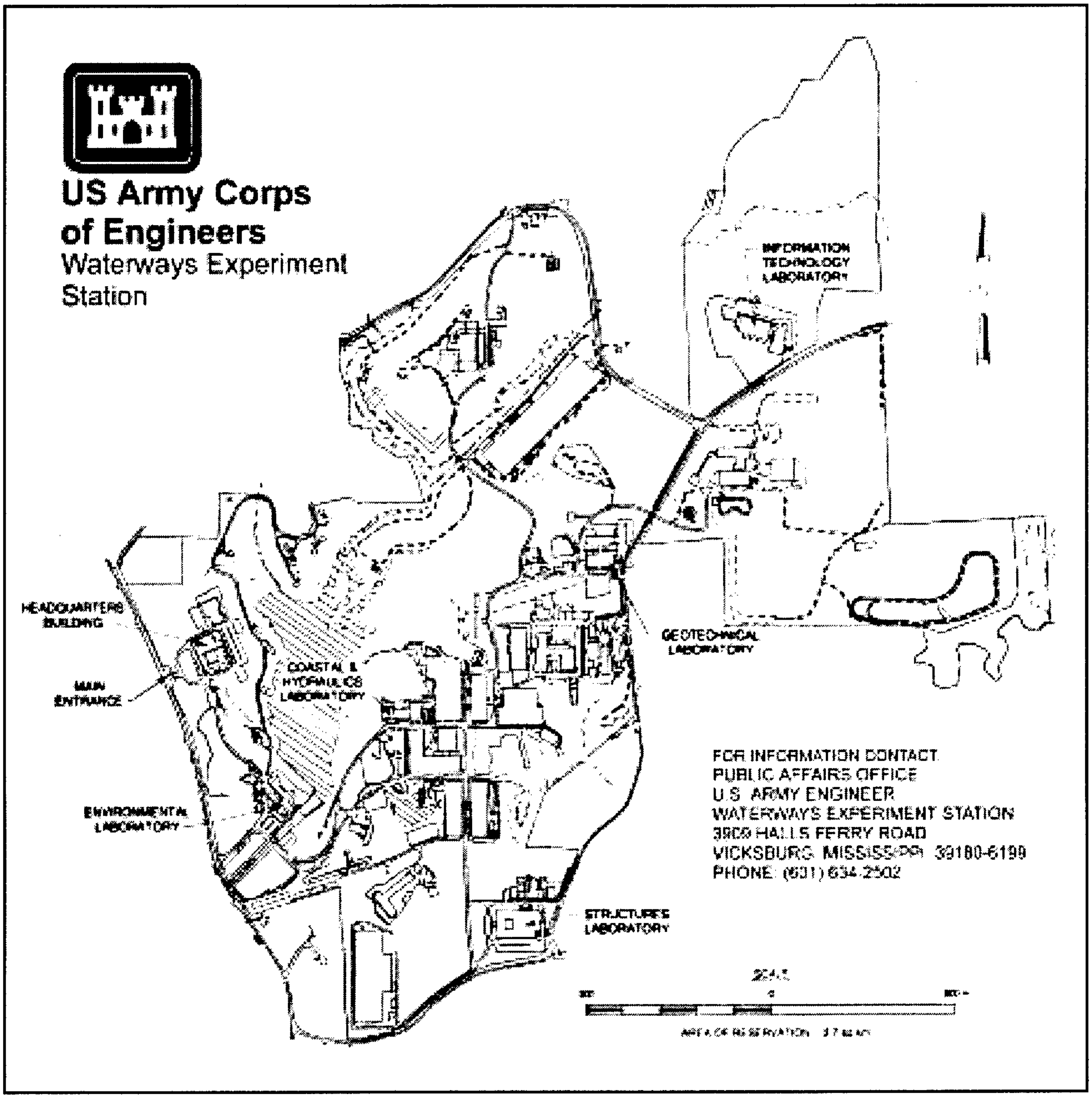

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Preface

The study reported herein was conducted as part of the Monitoring Completed Navigation Projects (MCNP) Program, formerly Monitoring Completed Coastal Projects Program. Work was conducted under Work Unit IM-7, "Periodic Inspections." Overall program management for MCNP is accomplished by the Hydraulic Design Section of Headquarters, U.S. Army Corps of Engineers (HQUSACE). The Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Waterways Experiment Station (WES), is responsible for technical and data management support for HQUSACE review and technology transfer. WES is a complex of five laboratories of the Engineer Research and Development Center (ERDC). Program Monitors for the MCNP Program are Messrs. Barry W. Holliday, Charles B. Chesnutt, and Michael J. Klosterman, HQUSACE. The Program Manager is Mr. E. Clark McNair, Jr., CHL.

This report is the second in a series that tracks the long-term structural response of the jetties at Manasquan Inlet, New Jersey, to their environment. The information contained in this report was gathered as a result of land and aerial survey work conducted by Aerial Data Reduction Associates, Inc., under contract to the Corps of Engineers, and a broken armor unit survey conducted by Messrs. Robert R. Bottin, Jr., and Larry R. Tolliver, CHL.

The work was conducted during the period July 1998 through December 1998 under the general supervision of Dr. James R. Houston, Director, CHL, and under direct supervision of Messrs. C. E. Chatham, Jr., Chief, Navigation and Harbors Division, and Dennis G. Markle, Chief, Harbors and Entrances Branch. This report was prepared by Mr. Bottin, CHL, and Mr. William F. Rothert, U.S. Army Engineer District, Philadelphia.

Commander of ERDC during the preparation and publication of this report was COL Robin R. Cababa, EN. This report was prepared and published at the WES complex of ERDC.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7646	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Monitoring Completed Navigation Projects Program

The goal of the Monitoring Completed Navigation Projects (MCNP) Program (formerly the Monitoring Completed Coastal Projects Program) is the advancement of coastal and hydraulic engineering technology. The program is designed to determine how well projects are accomplishing their purposes and are resisting attacks by their physical environment. These determinations, combined with concepts and understanding already available, will lead to creating more accurate and economical engineering solutions to coastal and hydraulic problems; to strengthening and improving design criteria and methodology; to improving construction practices and cost-effectiveness; and to improving operation and maintenance techniques. Additionally, the monitoring program will identify where current technology is inadequate or where additional research is required.

To develop direction for the program, the U.S. Army Corps of Engineers (USACE) established an ad hoc committee of engineers and scientists. The committee formulated the objectives of the program, developed its operational philosophy, recommended funding levels, and established criteria and procedures for project selection. A significant result of their efforts was a prioritized listing of problem areas to be addressed, essentially a listing of the area of interests of the program.

Corps offices are invited to nominate projects for inclusion in the monitoring program as funds become available. A selection committee, comprised of members of the MCNP Program Field Review Group (representatives from District and Division offices), reviews and prioritizes the projects nominated. The prioritized list is reviewed by the Program Monitors at Headquarters, U.S. Army Corps of Engineers (HQUSACE). Final selection is based on this prioritized list, national priorities, and the availability of funding.

The overall monitoring program is under the management of the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Waterways Experiment Station (WES), with guidance from HQUSACE. An individual monitoring project is a cooperative effort between the submitting District/Division office and

CHL. Development of monitoring plans and the conduct of data collection and analyses are dependent upon the combined resources of CHL and the District/ Division. The inspection for the study reported herein was completed as part of the "Periodic Inspections" work unit of the MCNP program.

Work Unit Objective and Monitoring Approach

The objective of the "Periodic Inspections" work unit in the MCNP Program is to monitor selected coastal navigation structures periodically to gain an understanding of the long-term structural response of unique structures to their environment. These periodic data sets are used to improve knowledge in design, construction, and maintenance of both existing and proposed coastal navigation projects. These data also will avoid repeating past design mistakes that have resulted in structure failure and/or high maintenance costs. Past projects monitored under the MCNP Program and/or structures with unique design features that may have application at other sites are considered for inclusion in the periodic inspections monitoring program. Selected sites are presented as candidates for development of a periodic monitoring plan. Once the monitoring plan for a site is approved and funds are provided, monitoring of the site is initiated. Normally, base conditions are established and documented in the initial effort. The site then is reinspected periodically (frequency of surveys is based on a balance of need and funding for each monitoring site) to obtain long-term structural performance data.

Relatively low-cost remote sensing tools and techniques, with limited ground truthing surveys, are the primary inspection tools used in the monitoring efforts. Most periodic inspections consist of capturing above-water conditions of the structure at periodic intervals using high-resolution aerial photography. Periodic aerial photographs are compared visually to gauge the degree of in-depth analysis required to quantify structural changes (primarily armor unit movement). Data analysis involves using photogrammetric techniques developed for and successfully applied at other coastal sites. At sites where local wave data are being gathered by other projects and/or agencies (these data can be acquired at a relatively low cost), wave data are correlated with structural changes. In areas where these data are not available, general observations and/or documentation of major storms occurring in the locality are presented along with monitoring data. Ground surveys are limited to the level needed to establish the accuracy of photogrammetric techniques.

When a coastal structure is photographed at low tide, an accurate permanent record of all visible armor units is obtained. Through the use of stereoscopic, photogrammetric instruments in conjunction with photographs, details of structural geometry can be defined at a point in time. By direct comparison of photographs taken at different times, as well as the photogrammetric data resolved from each set of photographs, geometric changes (i.e., armor unit movement and/ or breakage) of the structure can be defined as a function of time. Thus, periodic inspections of the structures will capture permanent data that can be compared

and analyzed to determine if structure changes are occurring that indicate possible failure modes and the need to monitor the structure(s) more closely. The jetties at Manasquan Inlet, New Jersey, were nominated for periodic monitoring by the U.S. Army Engineer District, Philadelphia (Philadelphia District).

Project Location and Brief History

Manasquan Inlet is located on the Atlantic Coast of New Jersey approximately 42 km (26 miles)[1] south of Sandy Hook and 37 km (23 miles) north of Barnegat Inlet (Figure 1). The inlet provides the northernmost connection between the ocean and the New Jersey Intracoastal Waterway. Reliable surveys as early as 1839 reveal that the inlet has migrated between its present location and 1.6 km (1 mile) north (Philadelphia District 1978). On a number of occasions prior to jetty completion in 1931, the inlet closed completely.

Stabilization of the inlet was first attempted between 1881 and 1883 with the construction of timber jetties. Both these and subsequent timber jetties built in 1922 failed, leading to Congressional authorization of the present project layout in 1930. The project involved construction of two rubble jetties, with steel sheet-pile cores, spaced 122 m (400 ft) apart. Built to a crest height of +4.3 m (+14 ft) mean low water (mlw),[2] the jetties extend to the -3-m (-10-ft) contour. The north jetty was 375 m (1,230 ft) long, and the south jetty was 314 m (1,030 ft) in length. Core stone weight ranged from 45.4 to 226.8 kg (100 to 500 lb), and 1,814-kg (2-ton) capstone was used for armor. Originally, the authorized channel was 76.2 m (250 ft) wide and 3 m (10 ft) deep between the jetties and 91.4 m (300 ft) in width and 2.4 m (8 ft) in depth for the interior channels. In 1935, the authorized channel depth between the jetties was increased to 4.3 m (14 ft) and the interior channel depth to 3.7 m (12 ft). The current project is shown in Figure 2.

Through the mid-1970s, the jetties were repeatedly damaged by storms and structural settlement (Philadelphia District 1978). Beach erosion north of the inlet and accretion to the south emphasized the impact of the jetties on the littoral system. Shoaling of the navigation channel increased as the structures deteriorated and became more permeable. Numerous repairs were attempted, using armor stone of up to 10,890 kg (12 tons), without success. Additional information relative to the repair and rehabilitation history of the jetties can be found in Smith (1988). A 1962 aerial view of the deteriorated jetties is shown in Figure 3.

A major rehabilitation of the jetties was completed in 1982 and involved the use of 14,515-kg (16-ton) reinforced dolos armor units (Figures 4 and 5).

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[1] Units of measurement in the text of this report are shown in SI (metric) units, followed by non-SI (British) units in parentheses. In addition, a table of factors for converting non-SI units of measurement used in figures in this report to SI units is presented on page vii.

[2] All elevations (el) and depths cited herein are in meters (feet) referred to mean low water (mlw).

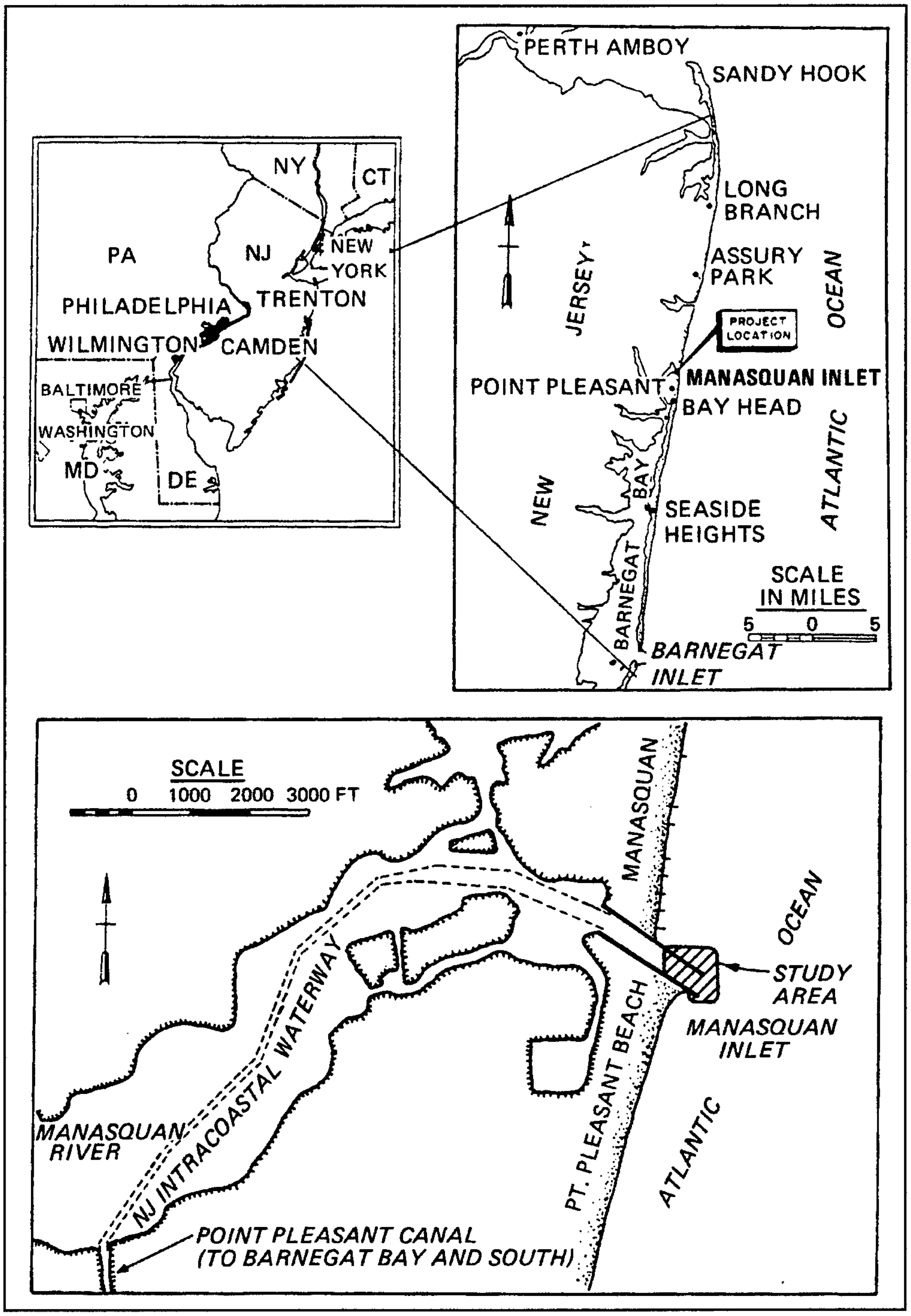

Figure 1. Location and vicinity map

Various views of a dolos armor unit are shown in Figure 6. Initial model experiments of the unit were performed by the South African Council for Scientific and Industrial Research in 1965 and indicated that dolosse had a stability coefficient higher than other armor units (Merrifield 1974). Subsequently, other laboratories, including the Corps of Engineers, experimented with dolosse and verified that they were more stable than natural stone and other existing concrete

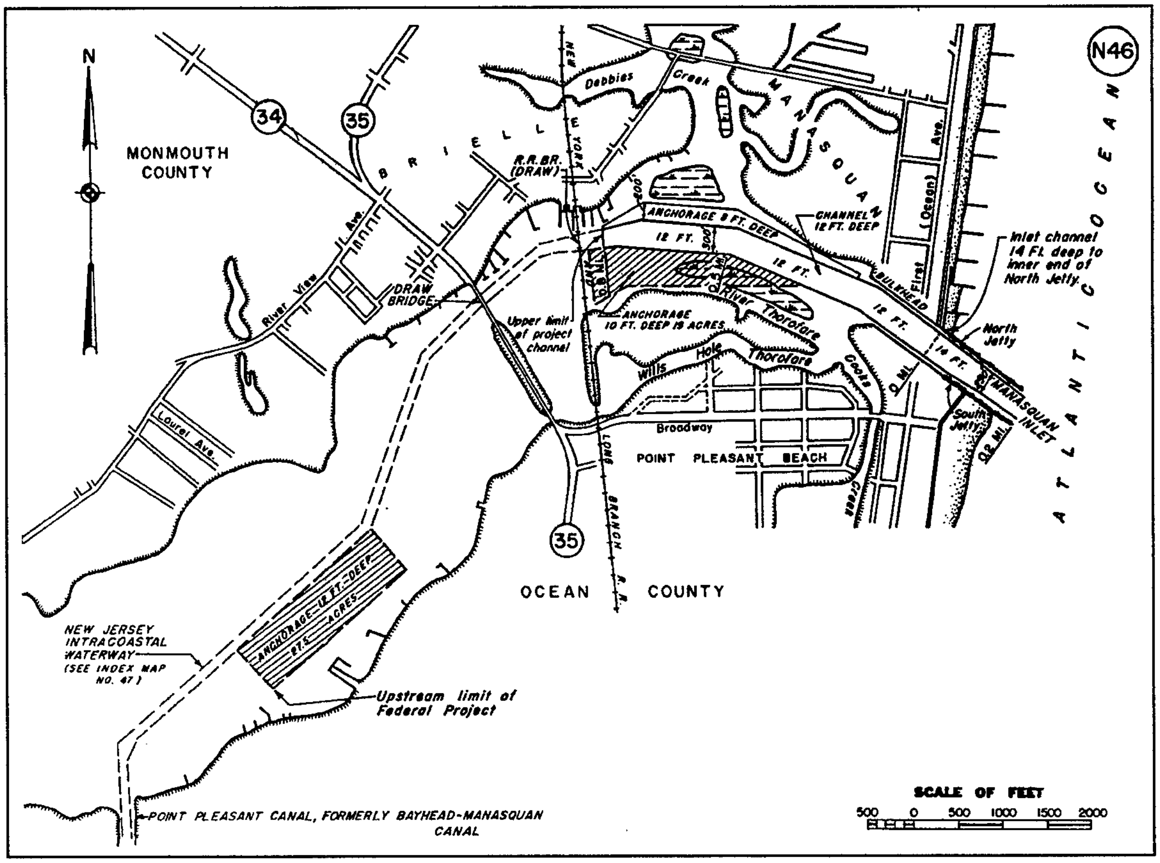

Figure 2. Manasquan Inlet, New Jersey

armor unit designs. Dolosse have been used on over 50 coastal projects throughout the world.

Rehabilitation was completed on the south jetty in 1980. The first step of the rehabilitation of the jetties was to disassemble them. Sand was excavated and dislodged armor stones were reshaped to the design configuration prior to dolos placement. Dolosse were placed on the outer 122 m (400 ft) of the north, or channel side of the jetty, around the structure head, and along the outer 36.5 m (120 ft) of the south side of the structure. Dolosse extended to -3 m (-10 ft) on the channel side at a slope of one vertical on two horizontal (1V:2H). Inshore of the dolos section, the side slopes were armored with a single layer of 10,885-kg (12-ton) stone. The outer 122 m (400 ft) of the jetty crest is a concrete cap; the inner portion of the jetty crest is 10,885-kg (12-ton) stone. The original sheet-pile core was left in place in its existing condition. The sheet pile extends the entire length of the jetty and has a top el of +2.4 m (+8 ft). Work on the north jetty began in 1980 and was completed in 1982. Dolosse were placed along the outer 76 m (250 ft) of the jetty on its north side, around its head, and along the outer 27.5 m (90 ft) on the channel side. Stone was used to armor the inner portions of the jetty on both sides. Construction drawings of typical cross sections for the jetties are shown in Figures 7 and 8.

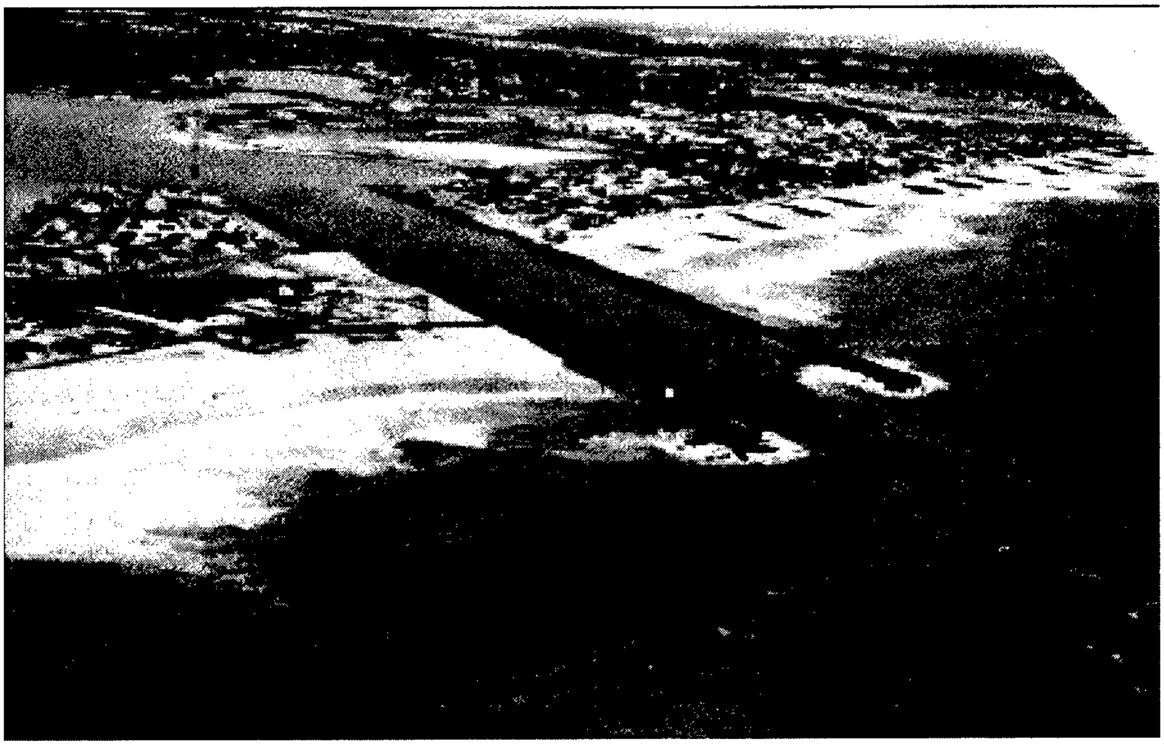

Figure 3. Aerial view of deteriorated jetties at Manasquan Inlet, March 1962

Breaking waves accompanied by storm surge were identified as the principal cause of damage to the structures at the inlet. Unfortunately, no reliable wave data existed at the site. Therefore, the design wave height was based on depth-limited breaking wave criteria. The design water depth at the seaward end of the jetties was calculated to be 8.8 m (29 ft), based on a mlw depth at the structure toe of 5.5 m (18 ft), plus 1.65-m (5.5-ft) maximum spring tide height, plus 1.65-m (5.5-ft) storm surge el. Using procedures from the *Shore Protection Manual* (SPM) (1984) for a range of wave periods from 7 to 15 sec and assuming a nearshore bottom slope of 0.01, values of the breaking wave height ranged up to 7.5 m (24.7 ft) for the longer wave periods. The design breaking wave height selected was, therefore, 7.6 m (25 ft). Several alternative designs were considered for the rehabilitation, including 10,885- and 18,145-kg (12- and 20-ton) stone and 14,515-kg (16-ton) dolosse. Dolosse were determined to have the lowest annual maintenance cost and were selected for construction. Based on engineering judgment, a decision was made to reinforce the dolosse with epoxy-coated reinforcing rods.

In 1995, maintenance was performed at the tip of the south jetty where core stone under the jetty cap was exposed. Nylon bags were placed in this area, and concrete was pumped into them as a temporary solution (Figure 9). A total of 53.5 cu m (70 cu yd) of concrete was used. This was the first maintenance performed on the jetties since the major rehabilitation was completed in 1982.

In October 1997, void areas in both jetties were rehabilitated with 17,235-kg (19-ton) CORE-LOC armor units. CORE-LOCs were developed by the Corps of

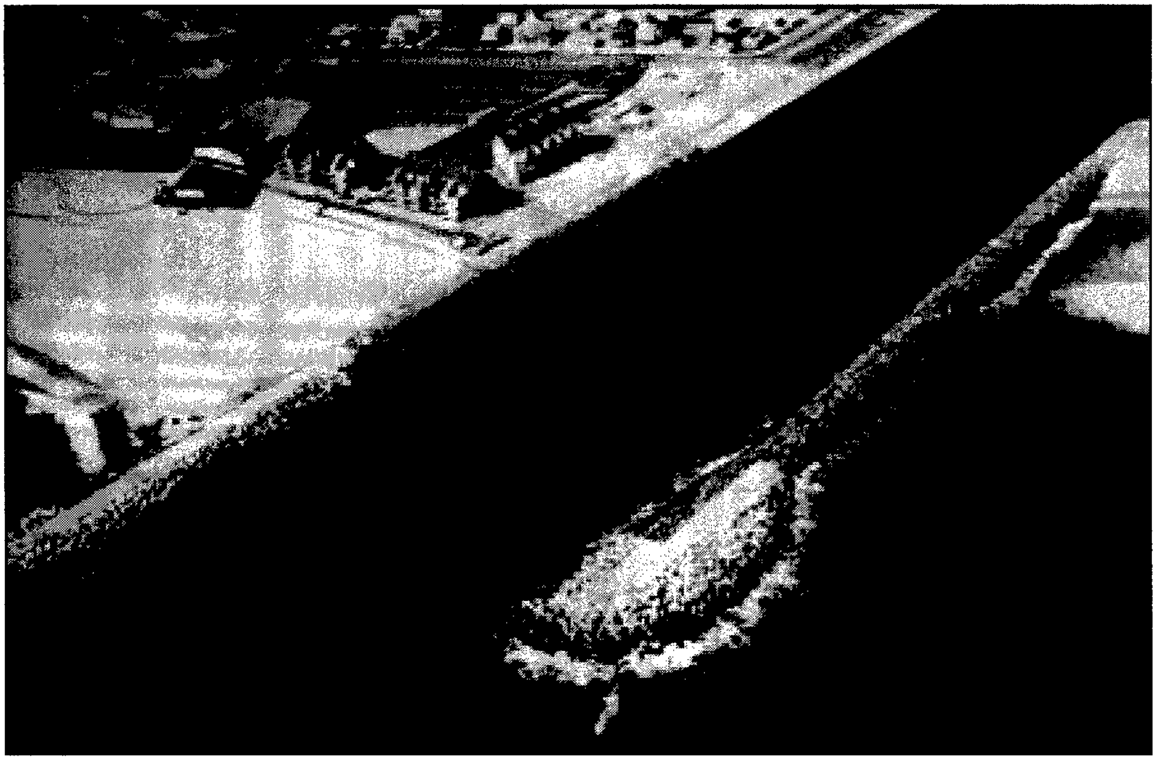

Figure 4. Aerial view of dolos at heads of jetties after 1982 rehabilitation

Engineers (USACE 1994) and were designed to be placed in a single layer on both steep and moderate slopes. The shape was designed to have much lower stresses than existing slender armor units and to produce an armor unit with very little rocking during design conditions. In addition, the unit was designed to be used as a repair for dolos slopes. Various views of a CORE-LOC armor unit are shown in Figure 10. This rehabilitation was the first application of CORE-LOCs in the United States. The selected CORE-LOC matched the same maximum dimension as the existing dolosse (3.4 m (11 ft)). The 2,720-kg (3-ton) weight increase was due to the third fluke in the middle of the shank. The CORE-LOCs were strengthened with reinforcing steel.

Twenty-nine CORE-LOCs were placed on the north jetty and 16 on the south jetty interlocking with the existing dolosse. In addition, nine dolosse were repositioned to improve the interlocking effect of the dolosse armoring, and several broken units were removed. Other dolosse were repositioned slightly to provide space for the new CORE-LOCs into the overall protection plan. A view of a CORE-LOC armor unit on the south jetty head is shown in Figure 11.

Figure 5. Closer view of 16-ton dolos armor units used on the heads of Manasquan Inlet jetties during 1982 rehabilitation

Purposes of the Study

The purposes of the study reported herein were as follows:

a. To develop methods using limited land-based surveying, aerial photography, and photogrammetric analysis to assess the long-term stability response of the concrete armor units on the Manasquan Inlet jetties.

b. To conduct land surveys, broken armor unit inspections, aerial photography, and photogrammetric analyses to test and improve developed methodologies and accurately define armor unit movement above the waterline.

c. To reexamine data obtained in previous monitoring efforts and determine and define any changes occurring to the dolos armor layers.

d. To establish baseline data for the recently installed CORE-LOC armor units.

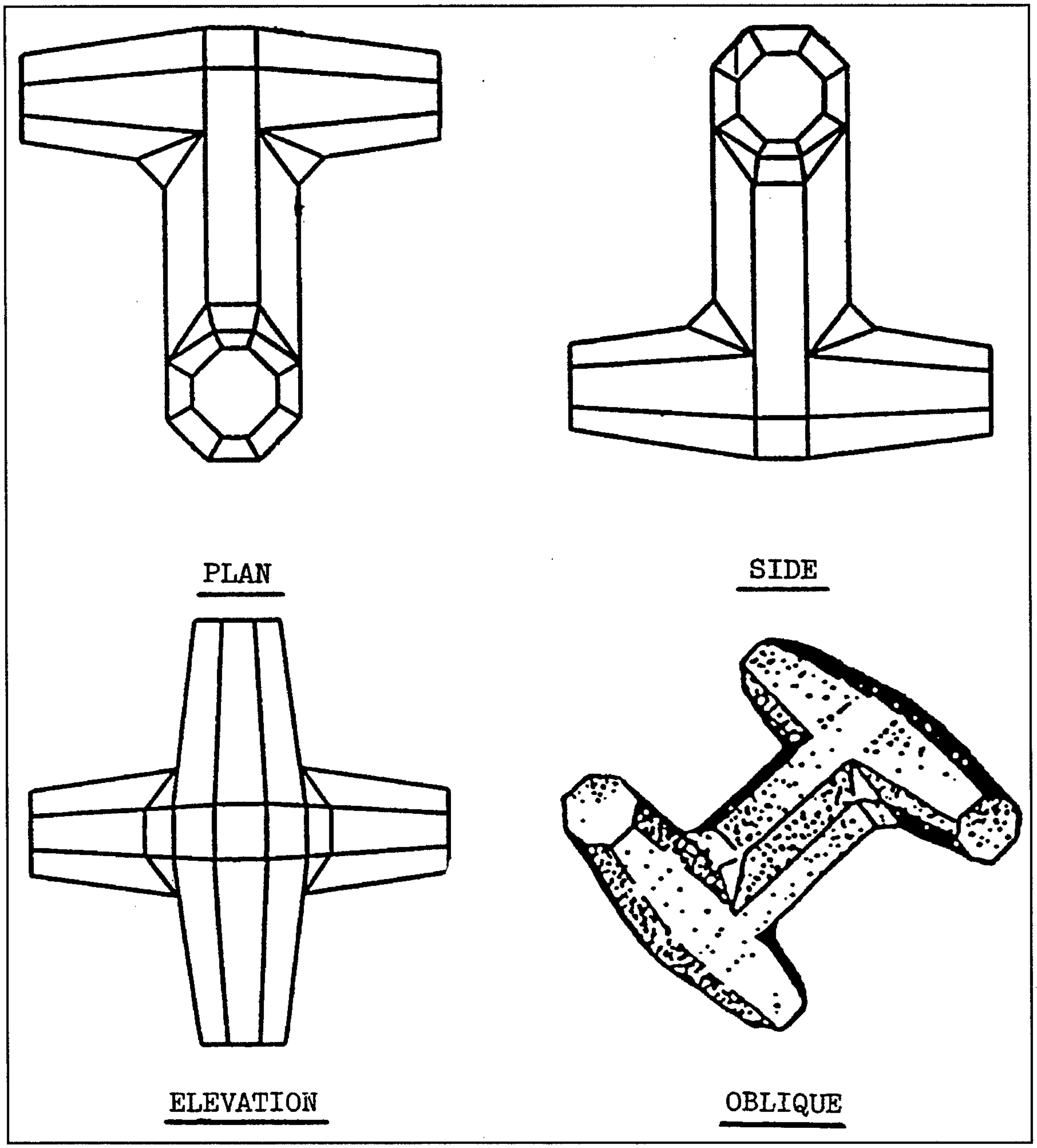

Figure 6. Various views of a dolos armor unit

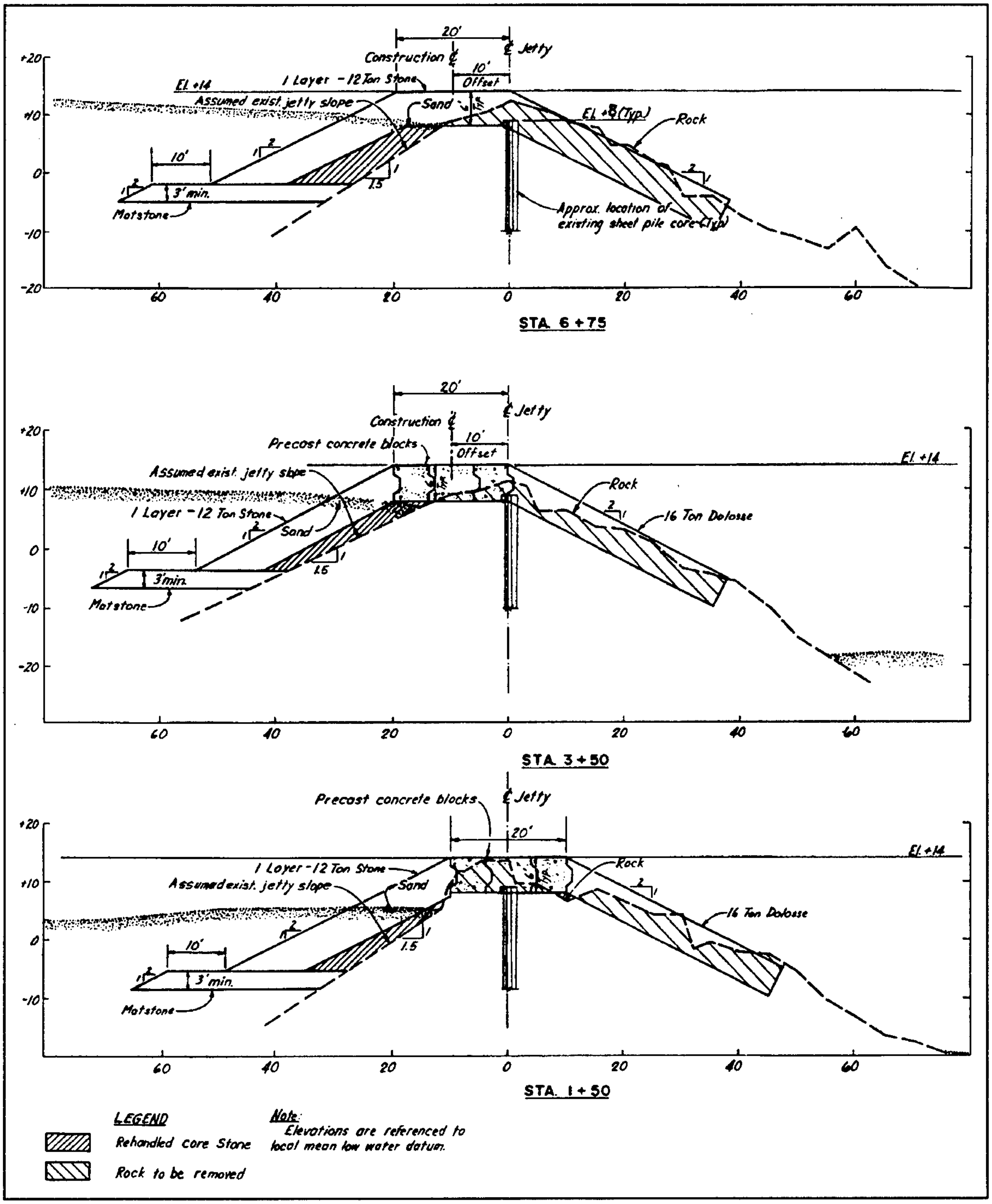

Figure 7. Construction drawings of south jetty cross sections, 1980 rehabilitation

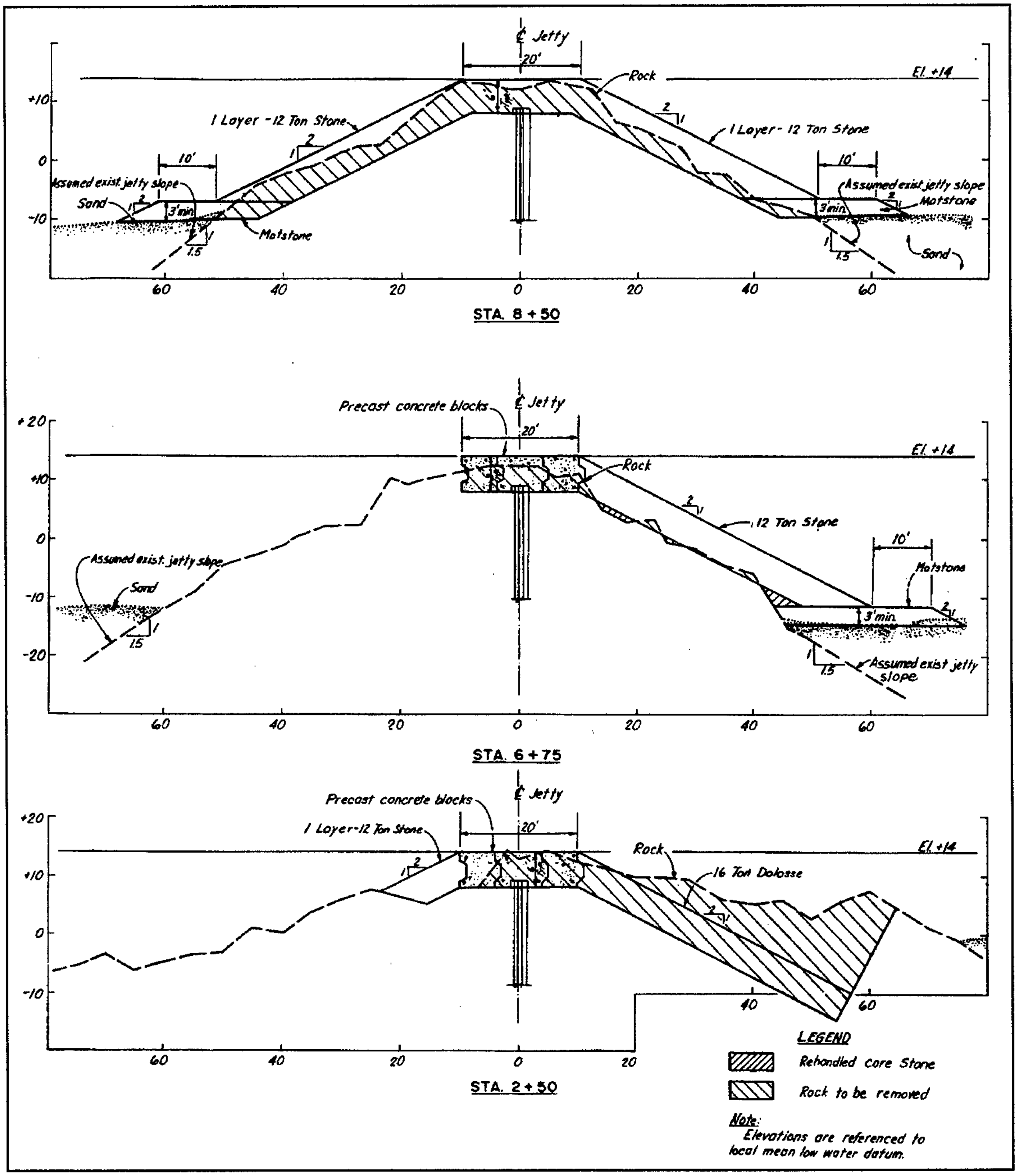

Figure 8. Construction drawings of north jetty cross sections, 1982 rehabilitation

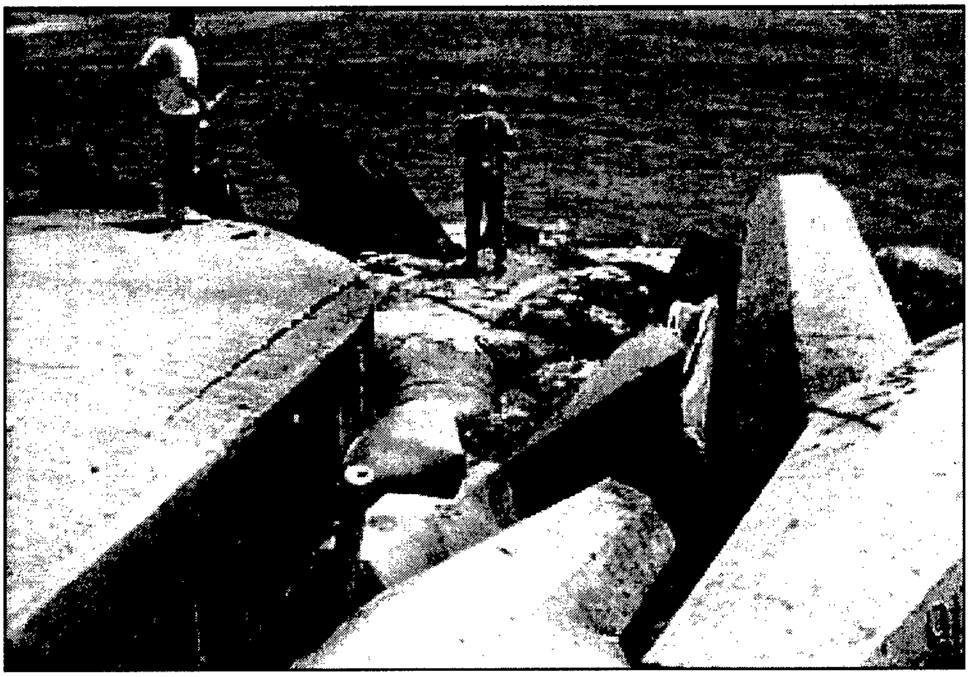

Figure 9. Emergency repair work (grout-filled bags) at head of south jetty (performed in 1995)

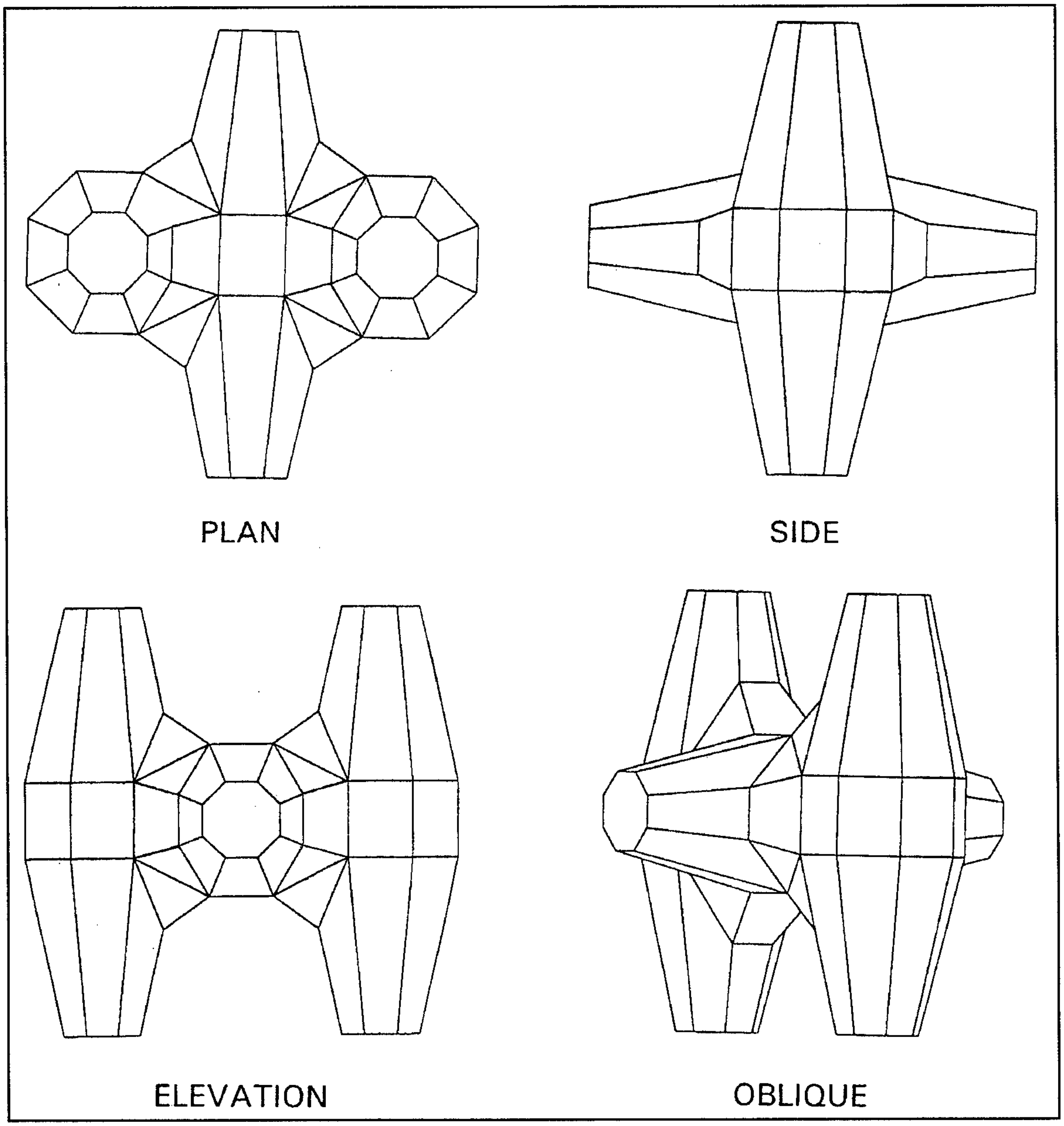

Figure 10. Various views of a CORE-LOC armor unit

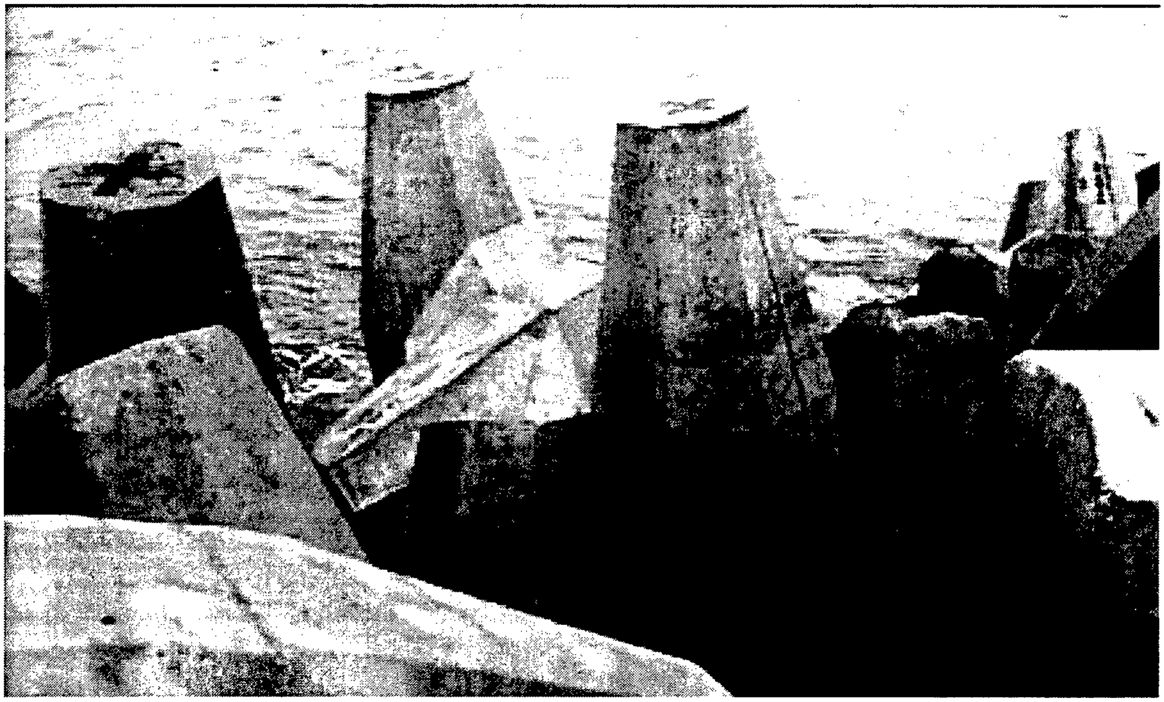

Figure 11. View of 17,235-kg (19-ton) CORE-LOC armor unit on head of south jetty after 1997 rehabilitation

2 Prior Monitoring of the Site

Initial (Comprehensive) Monitoring

General

The jetty rehabilitation project at Manasquan Inlet was selected for monitoring under the MCNP Program in 1982 during the second year of the program. The goal of the program is the advancement of coastal engineering technology. It is designed to determine how well projects are accomplishing their purposes and are resisting the attacks of the physical environment. The primary objective of the Manasquan Inlet jetties rehabilitation monitoring plan was to determine the stability of the jetties, particularly the dolos armor units. This was the first application of dolosse in the United States in the east coast environment. Additional objectives were to determine potential effects of the rehabilitated jetties on longshore sediment movement at the inlet and determine the effectiveness of the rehabilitated jetties in maintaining a stable inlet cross section.

Data collection for the monitoring program at Manasquan Inlet occurred from June 1982 to October 1984. The monitoring program incorporated the use of several observational, direct measure, and remote sensing methodologies. It included the collection of wave and tide data, hydrographic and beach surveys, aerial photography, photogrammetric analysis of armor unit movements, broken armor unit surveys, and underwater surveys utilizing side-scan sonar. Results of this study were published in Gebert and Hemsley (1991). Aerial photography, photogrammetric analysis of armor unit movements, and broken armor unit survey data, which are relative to the Periodic Inspections work unit, are summarized below.

Aerial photography

Aerial photography is a very effective means of capturing images of large areas for later analysis, study, visual comparison with previous or subsequent photography, or measurement and mapping. Its chief attribute is the ability to freeze a moment in time, while capturing great detail.

Black and white aerial photography was obtained from a fixed-wing plane at an altitude of 183 m (600 ft), resulting in a contact scale of 1:1,200. The photography was obtained with a precision cartographic camera, a Zeiss RMK A 15/23. Photographic stereo pairs were obtained during the flights. Aerial photography was obtained for the south jetty on 9 January 1982, 29 January 1983, 15 September 1983, 27 March 1984, and 9 May 1984. For the north jetty, aerial photography was obtained on 29 January 1983, 15 September 1983, 27 March 1984, and 9 May 1984. The photography was obtained after significant storm events during the course of the initial Manasquan Inlet monitoring program.

Prior to obtaining aerial photography, primary targets were established on stable portions of the jetties. They were surveyed in from nearby geodetic and vertical control benchmarks and were visible in the aerial photography. The primary targets on the jetties were located along the center lines of the concrete caps.

Photogrammetric analysis of armor unit movement

When aerial photography is planned and conducted so that each photo image overlaps the next by 60 percent or more, the two photographs comprising the overlap area can be positioned under an instrument called a stereoscope and viewed in extremely sharp three-dimensional detail. If properly selected survey points on the ground have previously been targeted and are visible in the overlapping photography, accurate measurements can be obtained of any point appearing in the photographs. This technique is called photogrammetry.

The stereo pair images obtained during aerial photography at Manasquan Inlet were viewed through a Kern PG 2-AT stereo restitution instrument, and stereo models were oriented to the target data previously obtained. The stereo models were used for compilation and development of plan view outlines of the dolosse and concrete cap. These features were superimposed on a grid based on the New Jersey State Plane Coordinate System, which graphically defined location and orientation of the features in the horizontal plane. Vertical data were recorded numerically at selected points on the dolosse. Photogrammetric maps developed from the stereo models were enlarged 20 times that of the contact scale, to a scale of 1:60.

The photogrammetric maps were plotted on transparent drafting material. The stability of dolosse from one flight to the next was determined by overlaying the two maps and visually comparing the location of individual dolosse. If a dolos moved during the time interval, the horizontal component of movement was evident, as a displacement of the outline occurred that was scaled from the 1:60-scale maps. The vertical component of movement was determined by comparison of spot elevations at selected points.

The initial maps of the north and south jetties were the most detailed prepared during the monitoring program. They documented the location, orientation, and

elevation of 754 dolosse, about 57 percent of the 1,326 units placed on the jetties during the rehabilitation. The remaining 43 percent were not mapped since they were either underwater or beneath the top layer of dolosse and not visible in the photography. A portion of the initial south jetty map is shown in Figure 12. Subsequent photogrammetric maps included smaller samples, thus reducing costs of map compilation while still obtaining representative coverage of the armor units on the two jetties.

A comparison of photogrammetry and standard ground-leveling data (ground truthing) for the initial photography suggested that the accuracy of the photogrammetrically derived elevations was on the order of ±0.09 m (±0.3 ft). Two factors were identified; however, that could have contributed to these differences. The first was that the time frames between ground truthing and photography differed by as much as 3 months. It was possible that dolos movement could have occurred during these periods contributing to the apparent differences between photogrammetric and leveling measurements of the same point. The second factor was that there were no visual targets on the dolosse to ensure that the survey crew and the photogrammetrist were observing exactly the same point when measuring an elevation. Features such as "center of face of vertical fluke" were the nominal targets used by the surveyors and photogrammetrist for identifying locations of spot elevations.

Prior to the September 1983 survey, 0.3-m (1.0-ft) black crosses were painted on 111 dolosse distributed over the two jetties, ensuring that both the field crew and the photogrammetrist would determine elevations at the same points on the units. Comparisons of the data demonstrated that 84 percent of the photogrammetric values were within ±0.03 m (±0.1 ft) of the elevations determined by ground truthing, and 98 percent were with ±0.06 m (±0.2 ft). These findings showed that photogrammetry was capable of accurately resolving slight movements of individual armor units that would permit a detailed evaluation of stability.

Ground truthing data were essential in verifying the accuracy of the photogrammetric elevations. However, these data do not provide any information on horizontal displacement, where both elevation and planimetric information are provided by photogrammetry.

As previously discussed, photogrammetric maps prior to September 1983 did not achieve as high a degree of accuracy in measuring dolosse movement as did later maps. However, an analysis of photogrammetric displacement data prior to September 1983 indicated that 65 percent of the observed points were within 0.09 m (0.3 ft) and 91 percent were within 0.3 m (1.0 ft) of their initial elevations. The maximum vertical change detected was a drop of 1.3 m (4.2 ft) on a dolos at the head of the south jetty. Ninety percent of the vertical displacements that exceeded 0.3 m (1.0 ft) occurred on dolosse at the heads of the two structures. The largest horizontal displacement detected was nearly 1.8 m (6.0 ft) on a dolos on the channel side of the south jetty. The next largest horizontal displacement was only 1.1 m (3.5 ft), occurring on the head of the south jetty. The mean horizontal movement of all monitored dolosse prior to September 1983

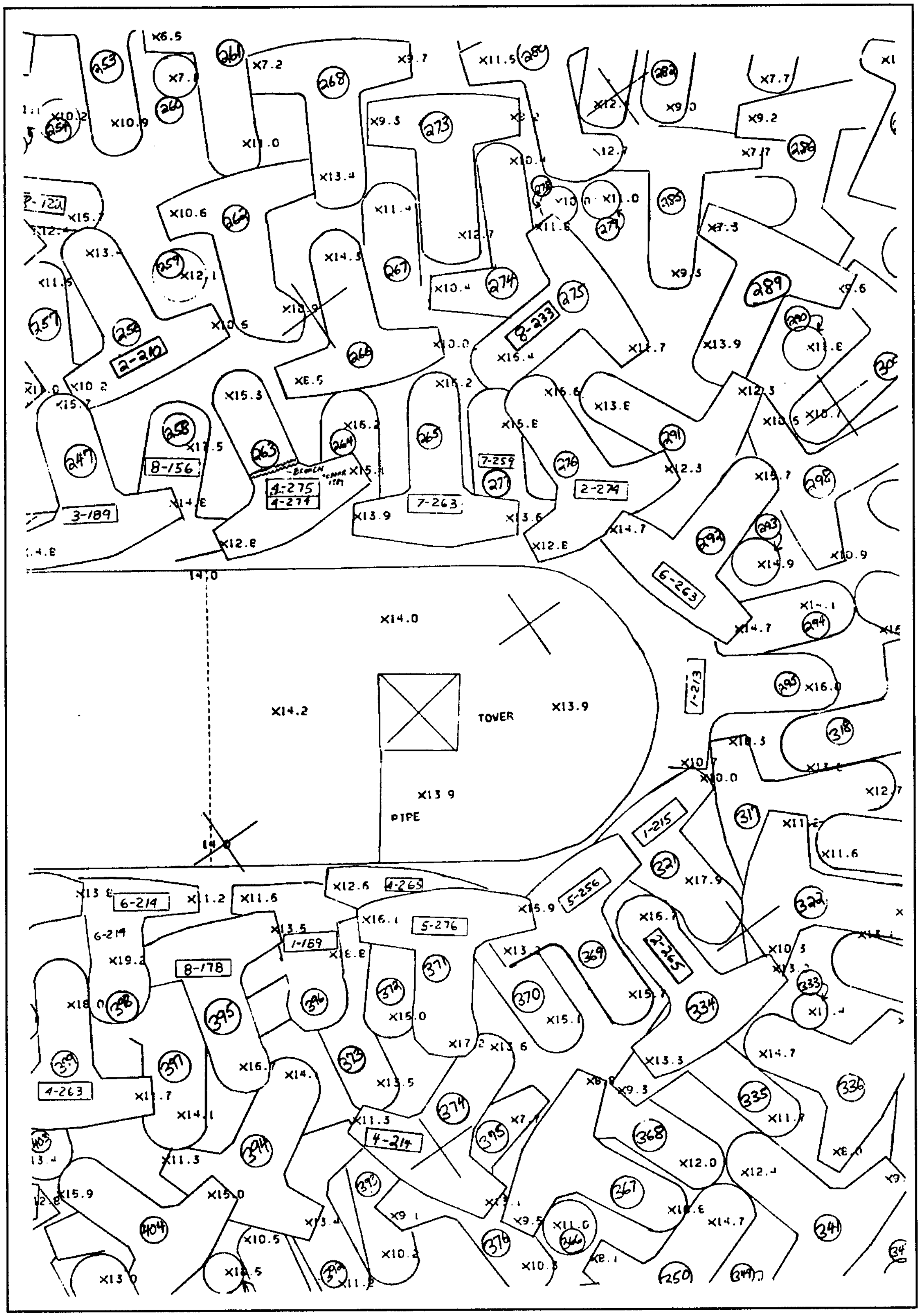

Figure 12. Portion of initial photogrammetric map of south jetty

was about 0.3 m (1.0 ft). The movements were predominantly displacement in a downslope direction. Displacement data suggested a relationship between armor unit movement and storm exposure. More movement was noted when storm conditions occurred between surveys as opposed to those during relatively storm-free periods.

All photogrammetric measurements on maps for the period September 1983 through May 1984 used targets (established in September 1983) and were assumed to be of comparable accuracy. The period between 15 September 1983 and 27 March 1984 was relatively storm free, whereas the interval between 28 March to 9 May 1984 was not. Measurements of vertical and horizontal displacements over these two intervals reinforced the earlier findings that dolos movements were predominantly related to storm events.

In the 6-month period from 15 September 1983 to 28 March 1984, the mean vertical displacement for all points monitored on the two jetties was 0.05 m (0.15 ft), and only 10 percent of the monitored dolosse experienced detectable horizontal displacements, the largest of which was about 0.3 m (1.0 ft).

Between 28 and 30 March 1984, an intense coastal storm affected the mid-Atlantic States. The gauge offshore at Manasquan revealed a maximum significant wave height of 6.7 m (22 ft) with a corresponding peak period of about 11.5 sec. The peak of the wave record coincided with the maximum tide stage, and thus exposed the jetties to what is believed to be the equivalent of the design storm. The significant wave height exceeded 6.1 m (20 ft) for 5 hr and 3.0 m (10 ft) for 30 hr.

The mean vertical displacement of all monitored dolosse because of the March 1984 storm was 0.14 m (0.46 ft). Approximately 3 percent of the dolosse moved in excess of 0.3 m (1.0 ft) vertically, with a maximum value indicating a 0.6-m (2.0-ft) drop. The largest horizontal displacement caused by the storm was 2.1 m (7.0 ft) at the head of the south jetty. There were three other dolosse that moved about 1.5 m (5.0 ft) horizontally. Altogether, only 9 percent of the monitored dolosse moved in excess of 0.6 m (2.0 ft) horizontally, with 31 percent moving up to 0.6 m (2.0 ft). About 60 percent of the dolosse experienced no detectable horizontal movement.

Broken armor units

As a result of the March 1984 storm, three dolosse broke on the north jetty, all within a zone about 10.7 m (35 ft) wide at the head of the structure. Two of the breaks resulted in loss of some concrete from the shank portions of the dolosse, but the presence of the epoxy-coated reinforcing steel kept the dolosse intact. One of these dolosse sustained significant damage, with considerable loss of concrete and reinforcing steel exposed in the break. Another dolos on the north jetty suffered a hairline crack through one fluke. As a result of the storm, one south jetty dolos, located near the head of the channel side of the structure,

broke at the junction of the shank and fluke. This dolos was still intact because of the reinforcing steel.

Prior to the March 1984 storm, one other dolos at the head of the north jetty had broken. Despite exposure to the design storm wave event, only 5 of the 1,326 dolosse (only 0.4 percent) used in the 1979-1982 rehabilitation had broken. It should be noted that of the five broken units, only one had experienced a net horizontal displacement in excess of 0.6 m (2.0 ft) from its initial location. Other dolosse had moved greater distances, up to 2.1 m (7.0 ft) between successive photography, yet had not broken. This finding suggested that movement alone may not be responsible for armor unit breakage. Impact may be more important than movement in dolos breakage. An armor unit may experience significant impacts even with only small movements.

Subsequent Armor Unit Monitoring (1984-1994)

Subsequent to the original monitoring effort of the dolosse at Manasquan Inlet through the MCNP Program, an additional photogrammetric survey was conducted in June 1992 using funds provided by the Philadelphia District. Detailed analyses of changes in armor unit positions between May 1984 and June 1992 data were not conducted because of limited resources (time and funds) in the Philadelphia District. An additional photogrammetric survey as well as a broken armor unit survey were completed in November 1994 as part of the Periodic Inspections work unit of the MCNP Program. Monuments and targets were reestablished, and limited ground-based surveys, aerial photography, and photogrammetric analyses were completed and compared with previous data to analyze the entire above-water armor unit fields and quantify armor unit movement. Detailed analyses regarding horizontal and vertical displacements were conducted not only for the targets established on the dolosse but for the entire armor unit. Comparisons were made for the 1984, 1992, and 1994 surveys. Also, using photogrammetric techniques, additional (nontargeted) dolosse were selected for analysis or armor unit movement between the 1984 and 1994 surveys. Detailed analyses and comparisons of armor unit movements are presented in Bottin and Gebert (1995). General findings are shown in the following paragraphs.

Results of the monitoring effort indicated that the dolosse on the north and south jetties have been dynamic since the initial monitoring program ended in May 1984. Between 1984 and 1994, horizontal movement ranged up to 2 m (6.6 ft) and vertical displacement (subsidence) as much as 1.6 m (5.3 ft). In general, however, most movements in both the horizontal and vertical directions were less than 0.3 m (1.0 ft). Data analysis indicated dolosse movement on the north jetty was slightly greater than the movement of units on the south jetty.

Horizontal movement for the majority of the dolosse was relatively uniform. The entire unit tended to migrate in the same direction as opposed to rotating. Of the units that rotated, however, the majority of those on the south sides of the

jetties tended to move in a clockwise direction, while those on the north sides of the jetties tended to rotate in counterclockwise directions. Units with the greatest horizontal displacements were concentrated along the inside head of the north jetty. Armor unit positions from photogrammetric maps also revealed missing armor units at the waterline along the head of the north jetty on its channel side.

Evaluation of the vertical motions of the armor units revealed that the majority of the dolosse on the jetties had subsided slightly. In general, the downslope portions of the armor units tended to subside more than the upslope portions. The horizontal flukes of the dolosse also tended to subside slightly more than the vertical flukes regardless of dolosse orientation on the jetty.

Evaluation of movement data indicated that both horizontal and vertical movements of the dolosse on the Manasquan Inlet jetties between 1992 and 1994 were greater than the 8-year period between 1984 and 1992. This was attributed to the occurrence of an unusual number of relatively intense extratropical storms ("northeasters") during the period October 1991 through March 1994 that impacted the coastline of the mid-Atlantic States, including the vicinity of Manasquan Inlet. During this period, three storm events—October 1991, December 1992, and March 1994—occurred that rank in the top 20 events at Atlantic City, NJ, covering a period of record back to 1911. In the same period, three storms—January 1992, December 1992, and March 1994—occurred at Lewes, DE, which rank in the top 10 storm events for the period of record back to 1919.

The 1994 broken armor unit survey revealed 17 broken/cracked dolosse as opposed to 5 in 1984. Of the 17 broken/cracked armor units observed, eight were located on the south jetty and nine were situated on the north structure. One unit had two separate breaks. Pieces of the armor units were separated on 10 dolosse. Four of the dolosse were broken/cracked and being held together by rebar, and four armor units had only hairline cracks. Overall, the rate of breakage since the dolosse rehabilitation has been limited. With 17 broken/cracked units of the 1,326 dolosse placed (assuming no breakage underwater), the breakage rate is only 1.3 percent. The only area of concern noted during the broken armor unit survey was at the tip of the south jetty where a broken unit resulted in exposure of core stone under the jetty cap.

Overall, the jetties appeared to be in good structural condition and were functioning as intended in 1994. To maintain the design cross-section stability of the structure, additional armor units were recommended for the void along the inside head of the north jetty and at the tip of the south jetty where the core stone was exposed.

3 Current Monitoring Plan and Data Comparison

The objective of the current monitoring effort in the Periodic Inspections work unit was to reexamine the dolosse portions of the Manasquan Inlet jetties and determine changes that have occurred since the last inspection in 1994. In addition, baseline conditions were to be obtained for the new CORE-LOC armor units installed during the October 1997 rehabilitation. The monitoring plan consisted of targeting, limited ground surveys, aerial photography, photogrammetric analysis of armor unit locations, a broken armor unit survey, and comparisons of current armor unit positions with those obtained previously.

Targeting and Ground Surveys

Monuments used previously were reestablished on the caps of the jetties to serve as control points (both horizontal and vertical reference) for ground-based survey work as well as photogrammetric work. Ground surveys were initiated from known monuments on shore. Using global positioning system (GPS) control surveying and electronic land-surveying techniques, monument positions were resurveyed in October 1998. Monument locations on the jetty caps are shown in Figure 13, and a typical monument is shown in Figure 14. Monuments used were brass disks cemented into the jetty cap. Positions and elevations of the most recently established monuments are shown in Table 1. Horizontal positions are based on the New Jersey State Plane Coordinate System, and all elevations are referenced to mean low water.

Horizontal and vertical position data obtained on monuments established during the August 1994 survey are shown in Table 2. Differences between the horizontal and vertical positions of the monuments established on the jetty caps are in Table 3 for the 1994 and 1998 surveys. As shown from the data in Table 3, horizontal shifts of the monuments on the concrete jetty caps have ranged from 0 to 0.073 m (0 to 0.24 ft) on the south jetty and from 0.003 to 0.024 m (0.01 to 0.08 ft) on the north structure since 1994. The data also indicate a slight subsidence or settlement of the north jetty cap. From 1994 to 1998, data reveal that monuments on the north jetty had subsided from 0.006 to 0.009 m (0.02 to

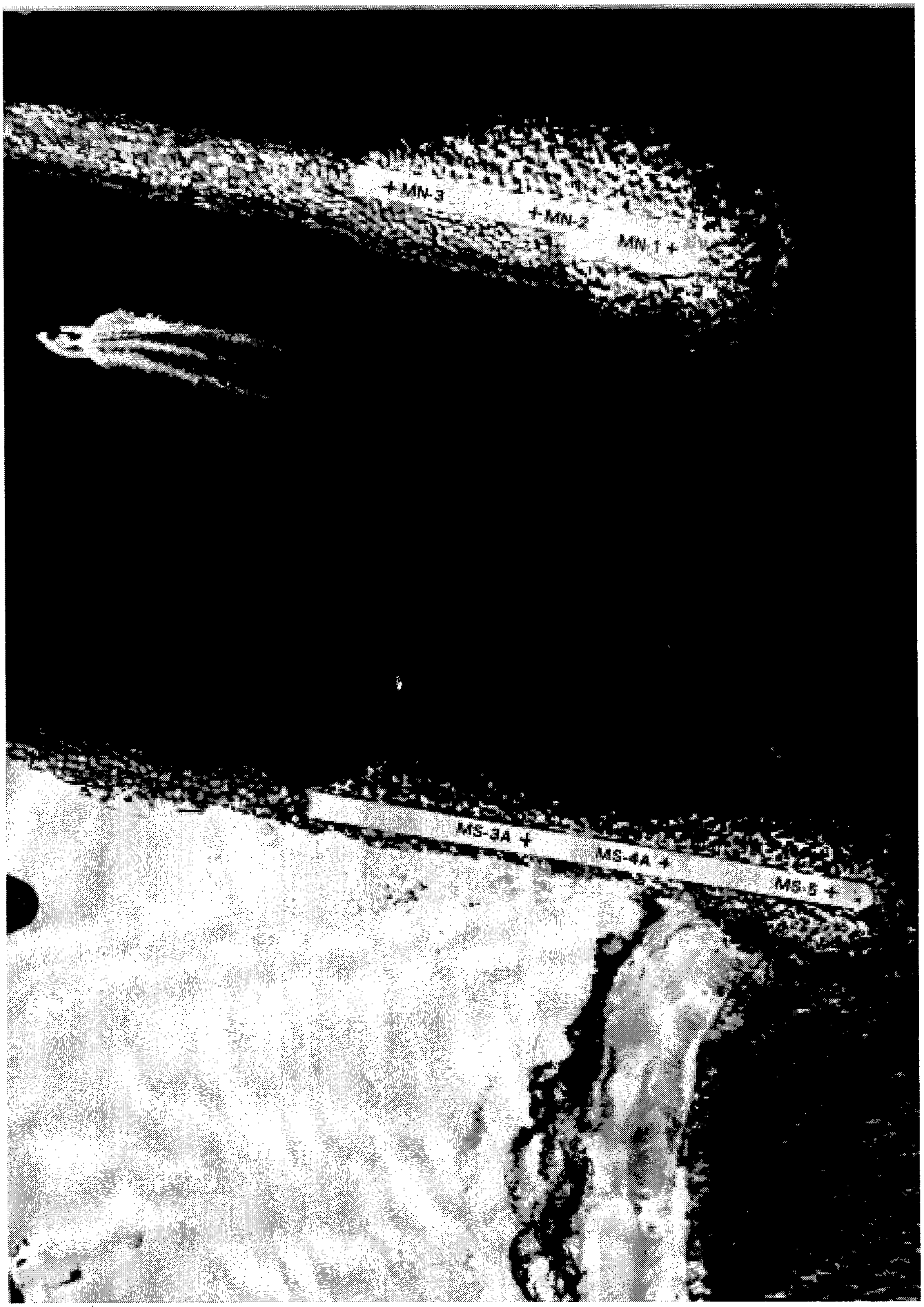

Figure 13. Locations of monuments on jetty caps

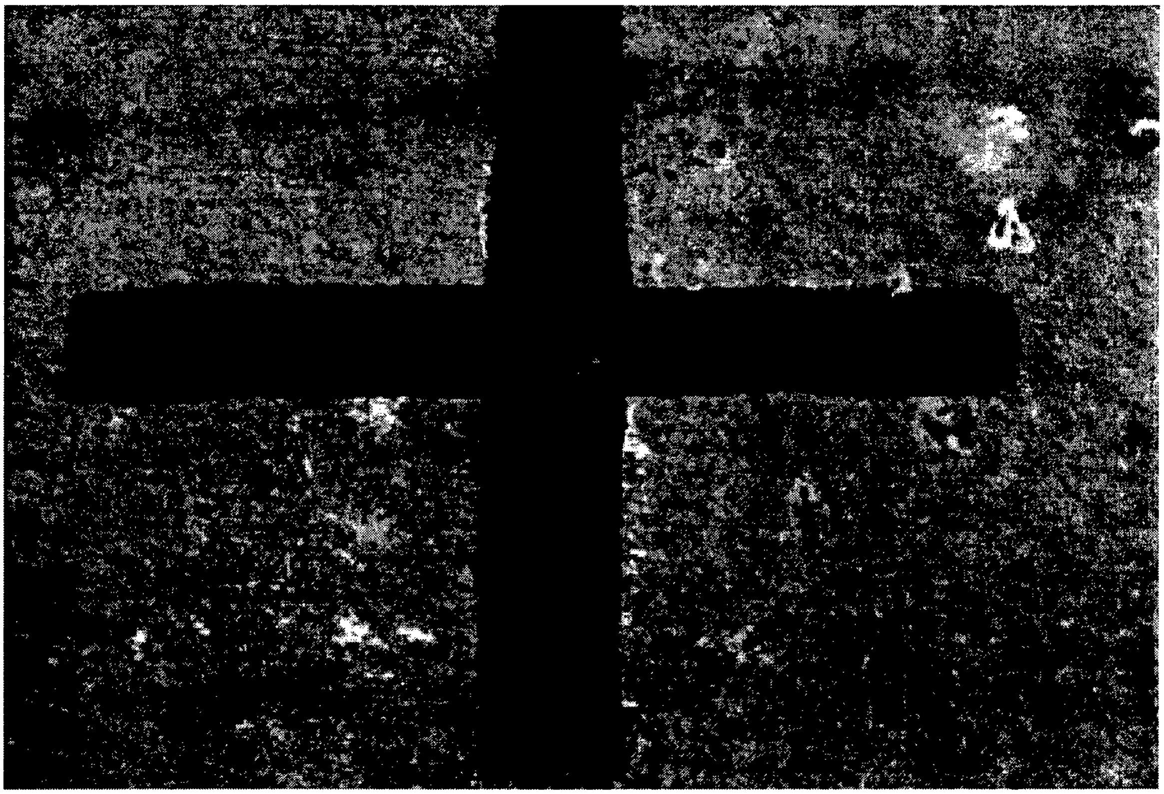

Figure 14. Example of a monument established on jetty cap

Table 1
Positions and Elevations of Monuments

Monument	1998 Coordinates		1998 el, m (ft)
	Northing	Easting	
North Jetty Cap			
MN-1	N462562.15	E2177592.84	+4.87 (+13.98)
MN-2	N462623.90	E2177516.54	+4.21 (+13.83)
MN-3	N462680.17	E2177433.97	+4.26 (+13.96)
South Jetty Cap			
MS-3A	N462232.87	E2177320.37	+4.25 (+13.95)
MS-4A	N462176.24	E2177403.28	+4.24 (+13.90)
MS-5	N462107.26	E2177504.20	+4.27 (+14.00)

Table 2
Position Data Obtained During the 1994 Survey

Monument	1994 Coordinates		1994 el, m (ft)
	Northing	Easting	
North Jetty Cap			
MN-1	N462562.20	E2177592.77	+4.27 (+14.00)
MN-2	N462623.88	E2177516.50	+4.22 (+13.85)
MN-3	N462680.17	E2177433.89	+4.26 (+13.99)
South Jetty Cap			
MS-3A	N462232.84	E2177320.33	+4.25 (+13.95)
MS-4A	N462176.24	E2177403.29	+4.24 (+13.91)
MS-5	N462107.30	E2177503.96	+4.26 (+13.99)

Table 3
Differences Between Horizontal and Vertical Positions of Monuments

Monument	Northing	Easting	Elevation
Difference from 1994 to 1998, m (ft)			
MN-1	0.015 (0.05)	0.021 (0.07)	-0.006 (-0.02)
MN-2	0.006 (0.02)	0.012 (0.04)	-0.061 (-0.02)
MN-3	0.003 (0.01)	0.024 (0.08)	-0.009 (-0.03)
MS-3A	0.009 (0.03)	0.012 (0.04)	0 (0)
MS-4A	0 (0)	0.003 (0.01)	0 (0)
MS-5	0.014 (0.04)	0.073 (0.24)	0.003 (0.01)

0.03 ft). On the south jetty, vertical changes in monuments ranged from 0 to 0.003 m (0 to 0.01 ft).

In addition to the monuments, targets were reestablished on the dolosse that corresponded with those established in previous surveys. A total of 111 dolosse, distributed over the two jetties, were initially targeted with 0.3-m (1.0-ft) painted black crosses to ensure visibility in the aerial photography. Of these, 51 targets were established on the north jetty with 60 targets on the south jetty. For the current (1998) survey, 44 of the original 51 targets on the north jetty and 57 of the original 60 targets on the south jetty were recovered and reestablished with the 0.3-m (1.0-ft) black crosses. Some of the unrecovered targets were on armor units located at the edge of the water and could not be reestablished during ground surveys because of the slippery algae growing on the dolosse. Others

were inadvertently missed. The actual locations of the targeted dolosse distributed over the north and south jetties are shown in Figures 15 and 16, respectively. Numbers correspond to the originally established targets. Targets also were established on the new CORE-LOC armor units installed on the heads of the jetties during the October 1997 rehabilitation. Sixteen CORE-LOCs on the north jetty and 12 on the south jetty were targeted. Their locations are shown in Figures 17 and 18. In addition to the painted black crosses, the center of each target was marked with a drill hole 0.64 cm (0.25 in.) in diameter and 0.64 cm (0.25 in.) deep to aid in identifying targeted units in subsequent surveys. A typical target established on an armor unit is shown in Figure 19.

Aerial Photography

Aerial photography was obtained on the jetties with a Wild RC30 aerial mapping camera (9- by 9-in. format). The photographs were secured from a fixed-wing aircraft flying at low altitude (183 m (600 ft)), which resulted in high-resolution images and contact prints with scales of 1:1,200. Photographic stereo pairs for the jetties obtained during the flights are shown in Figures 20-22. The seaward photograph image (Figure 20) was used with the middle image (Figure 21), and the landward image (Figure 22) was used with the middle image (Figure 21) in the stereo viewer to develop stereo models. The aerial photography was obtained on 5 November 1998.

Photogrammetric Analysis of Armor Units

The stereo pair images obtained during aerial photography at Manasquan Inlet were viewed in a Zeiss P3 Planicomp Analytical Stereo Plotter, and stereo models were oriented to the monument data previously obtained. In the stereo model, very accurate horizontal and vertical measurements can be made of any point on any armor unit appearing in the print. After orientation of the stereo model with monument data, x, y, and z coordinates were determined for the established targets. As indicated earlier, the accuracy of this technique was on the order of ±0.03 m (±0.1 ft) for the majority of the units. In addition to the data obtained on the targets, additional horizontal and vertical position data were obtained at other points on various dolosse through the stereo model. Without a visual target, the accuracy of these analyses was on the order of ±0.09 m (±0.3 ft). Analyses and comparisons of dolosse armor unit movement data from the 1994 and 1998 photogrammetric surveys are presented later in this part of the report as well as initial CORE-LOC armor unit target position data.

Photogrammetric maps were developed from the stereo models, similar to those done in earlier surveys. Tracings of plan view outlines of the visible armor units as well as vertical data at various points were plotted that were 20 times that of the stereo pair contact scale, to a scale of 1:60. In addition, rectified photographs (orthophotos) of the jetties were prepared from the stereo model at a scale of 1:300. Orthophotos combine the image characteristics of a photograph

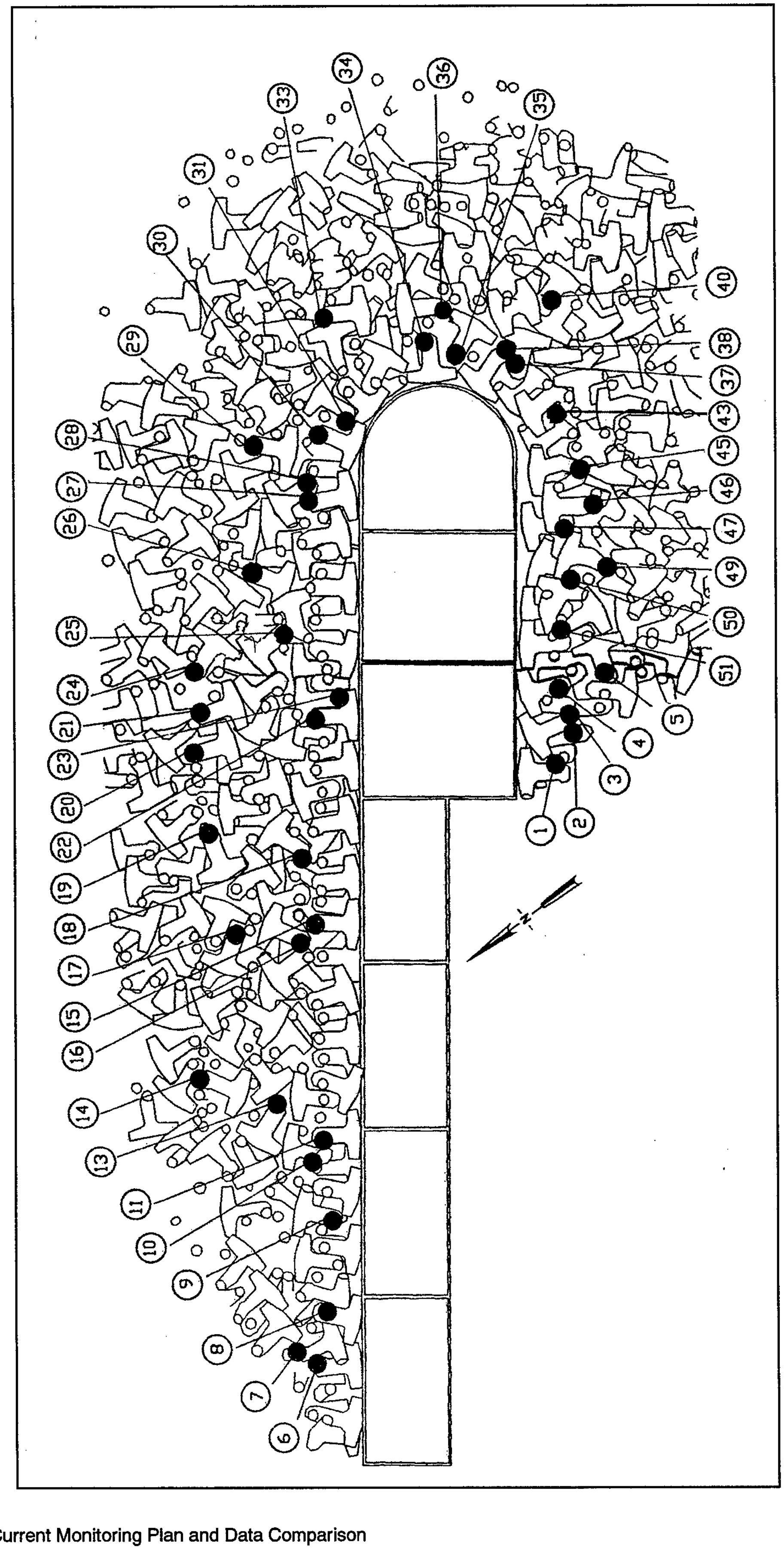

Figure 15. Locations of targeted dolosse on north jetty

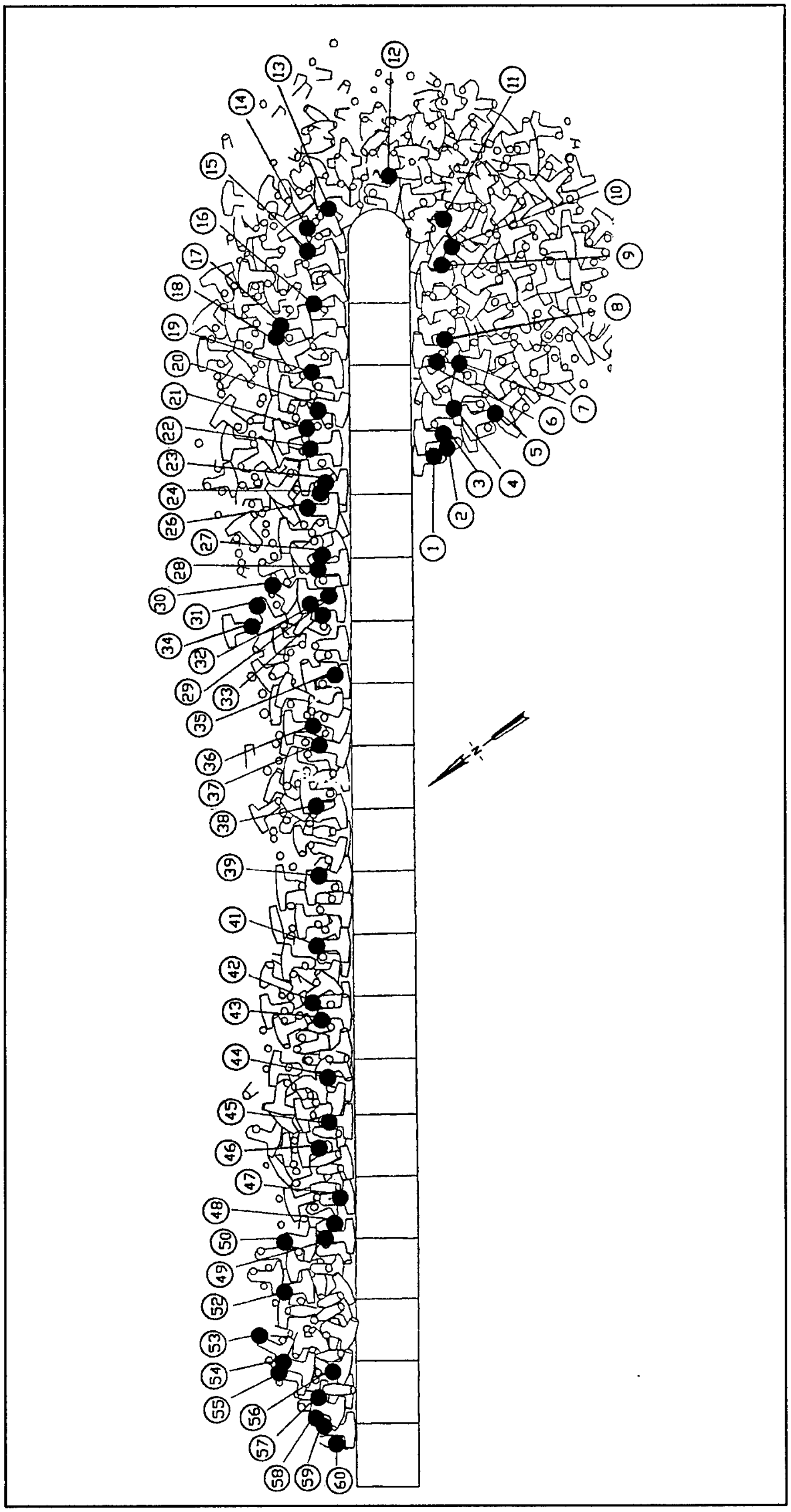

Figure 16. Locations of targeted dolosse on south jetty

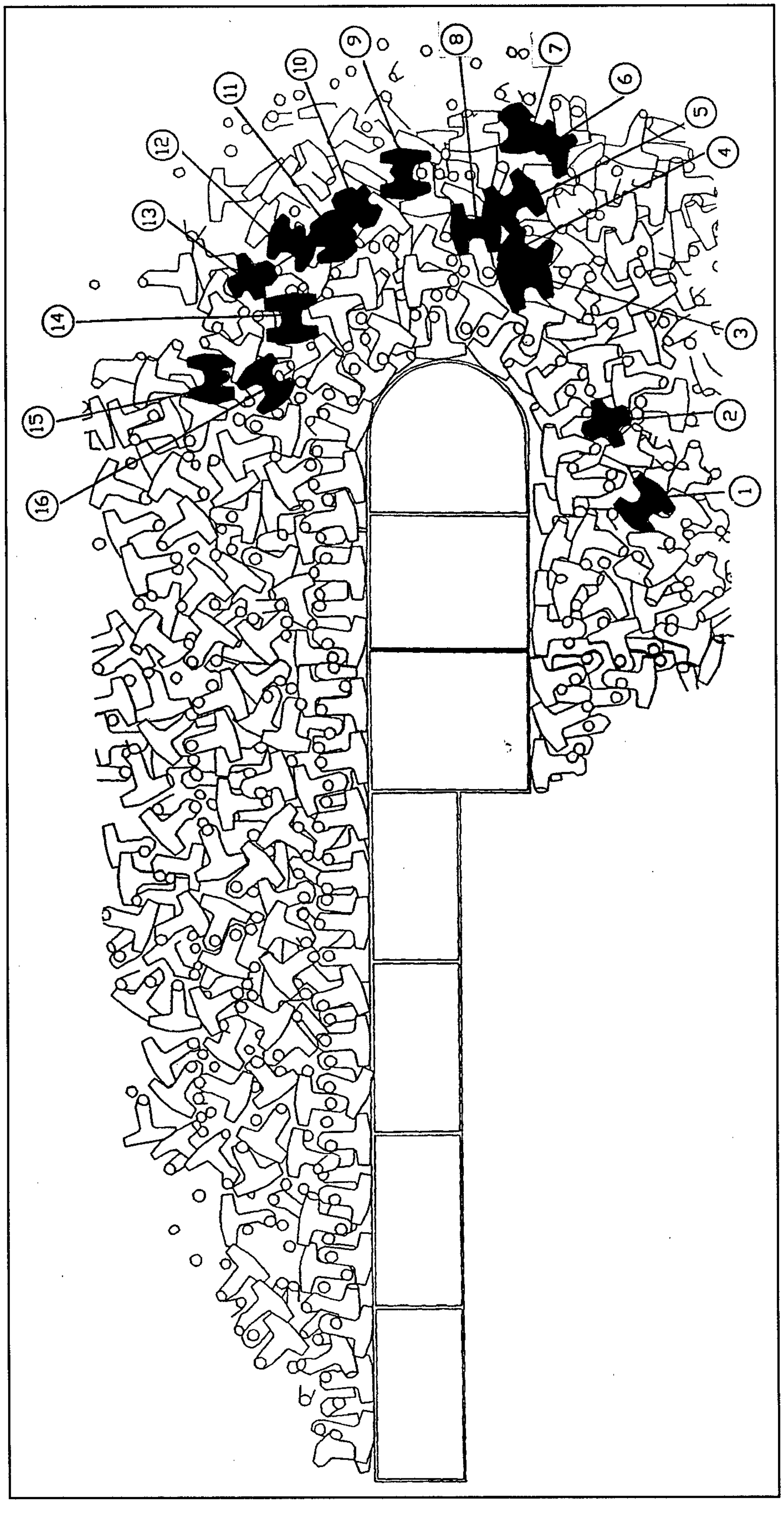

Figure 17. Locations of targeted CORE-LOCs on north jetty

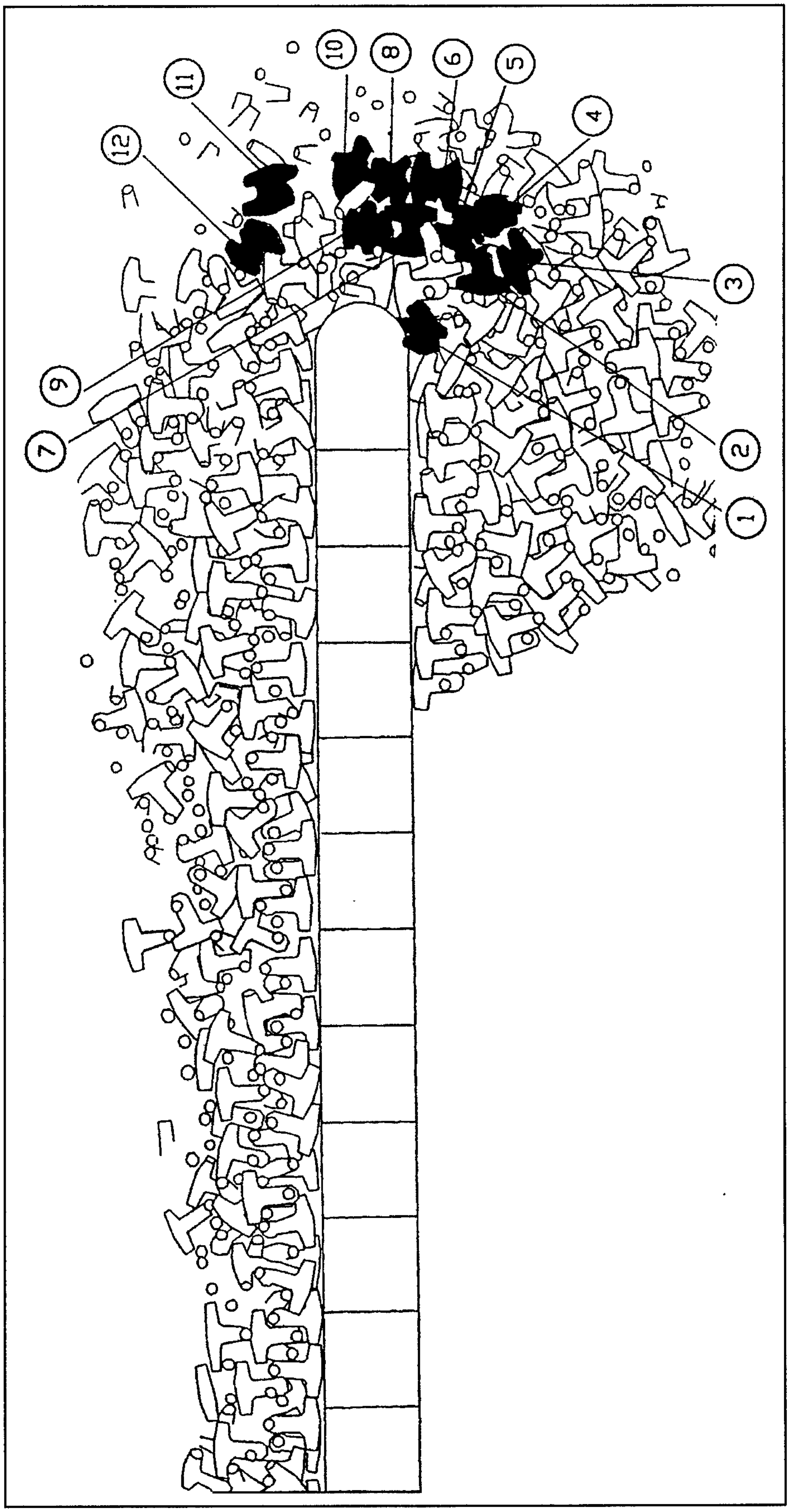

Figure 18. Locations of targeted CORE-LOCs on south jetty

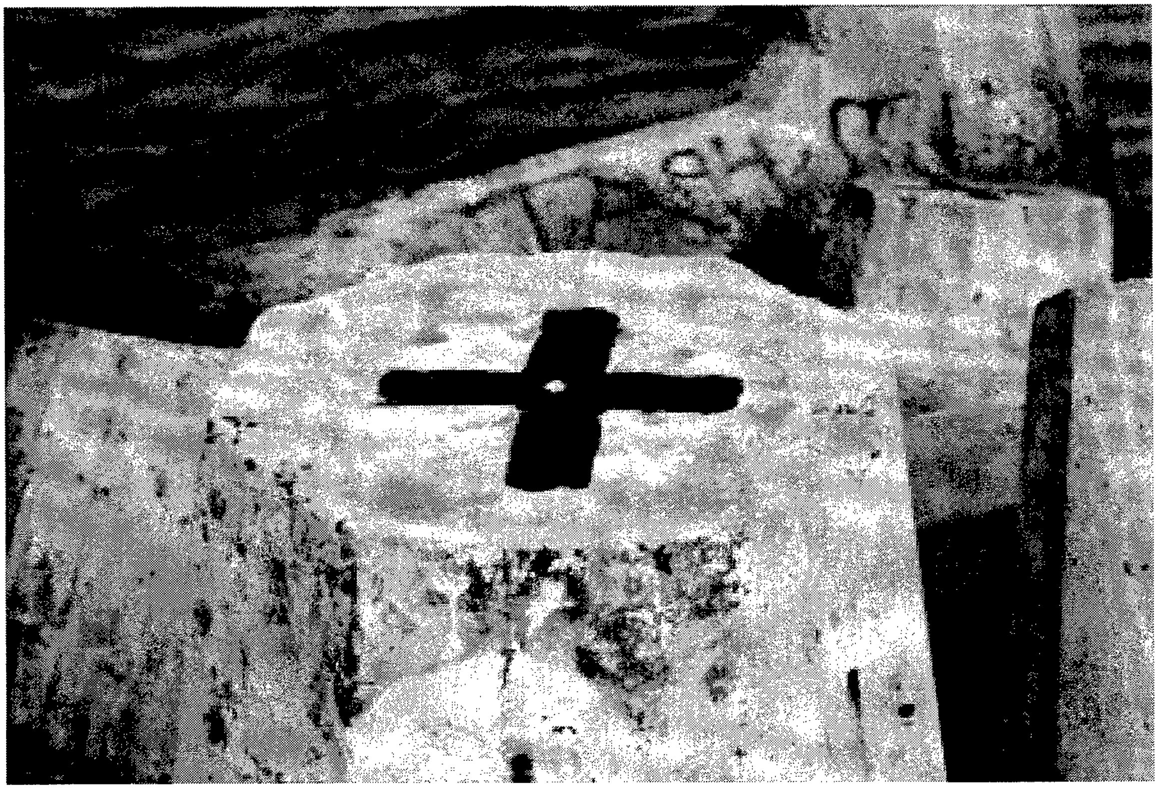

Figure 19. Typical target established on an armor unit

with the geometric qualities of a map. Precise horizontal measurements may be obtained from the orthophotos using an engineer scale since the image has been rectified and is free from skewness and distortion.

Full-scale hard copies of aerial photographs, photogrammetric maps, and orthophotos are on file at the authors' offices at WES and the Philadelphia District. In addition, all photogrammetric compilations and analyses and map data have been stored on diskettes in AutoCad files for future use. In summary, very detailed and accurate information relative to the armor unit positions at the Manasquan Inlet jetties have been captured by means of aerial photography and photogrammetric analysis. Data are stored on diskettes and can be retrieved and compared against data obtained during subsequent monitoring. Thus, armor unit movement data may continue to be quantified precisely in future years.

Broken Armor Unit Survey

On 17 November 1998, a survey of broken/cracked dolos armor units above the waterline on the Manasquan Inlet jetties was conducted. During the inspection, each broken armor unit was identified and photographed, and its approximate location relative to breakwater sta and offset from the concrete jetty cap was recorded. In addition, the dolosse number and date of casting, if visible, as well as the type of break were recorded. Types of breaks included shank and

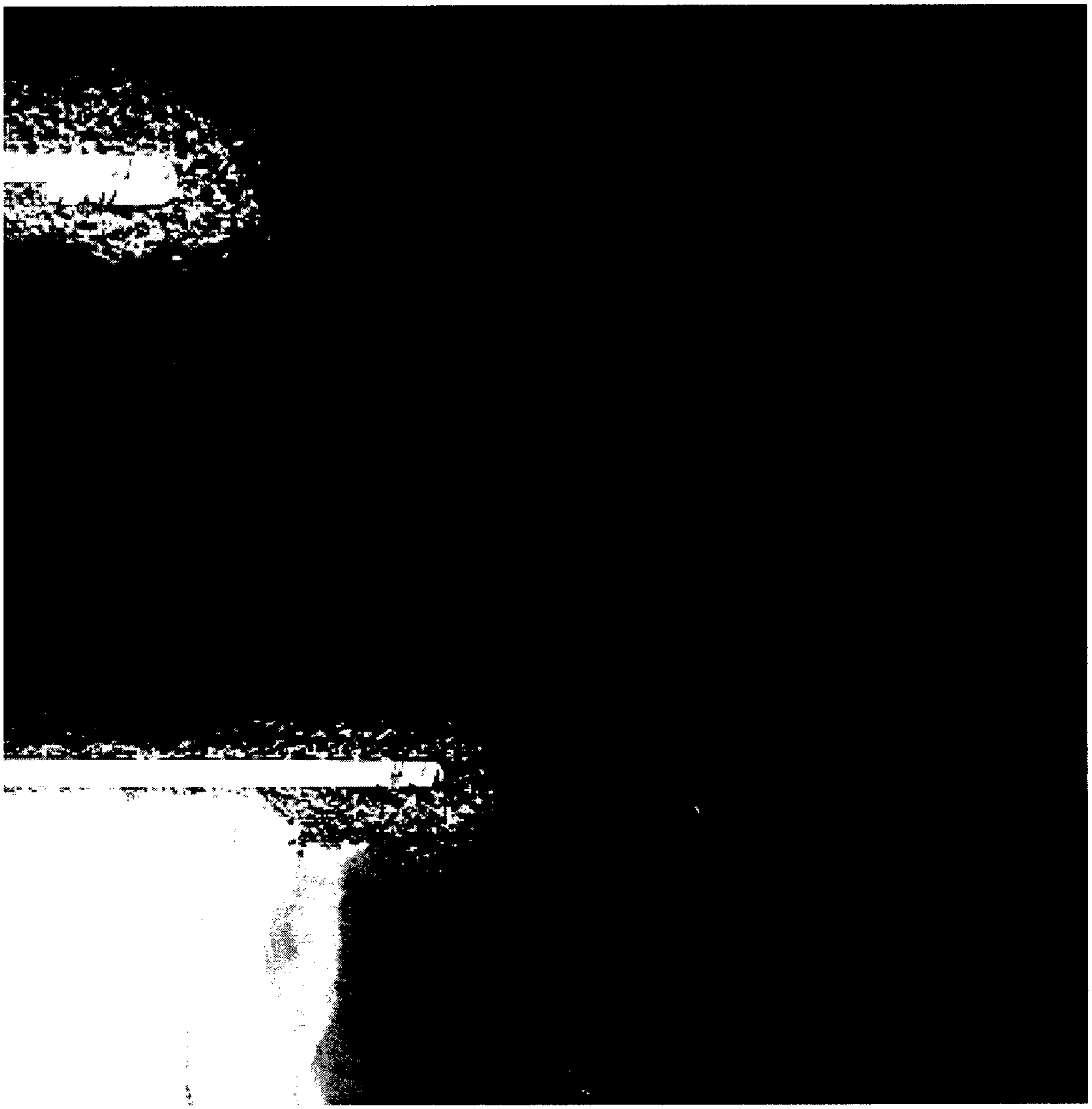

Figure 20. Stereo pair photograph for Manasquan Inlet jetties (seaward photograph image)

fluke breaks. They were characterized as midshank, shank-fluke (shank broken in vicinity of fluke), and fluke-shank (fluke broken off at junction with shank). Also recorded were straight breaks (broken straight across) and angled breaks (broken at some angle to the dolos limb). The water was relatively clear during the survey, and the tide level was low.

As stated earlier, 17 broken/cracked dolos armor units were identified during the November 1994 survey, mostly around the heads of the jetties. During the October 1997 CORE-LOC jetty rehabilitations, however, several broken dolos were removed from the heads of the structures. As a result, the current (November 1998) survey revealed eight broken/cracked dolos armor units on the Manasquan Inlet jetties. Four units were observed on each jetty, and their

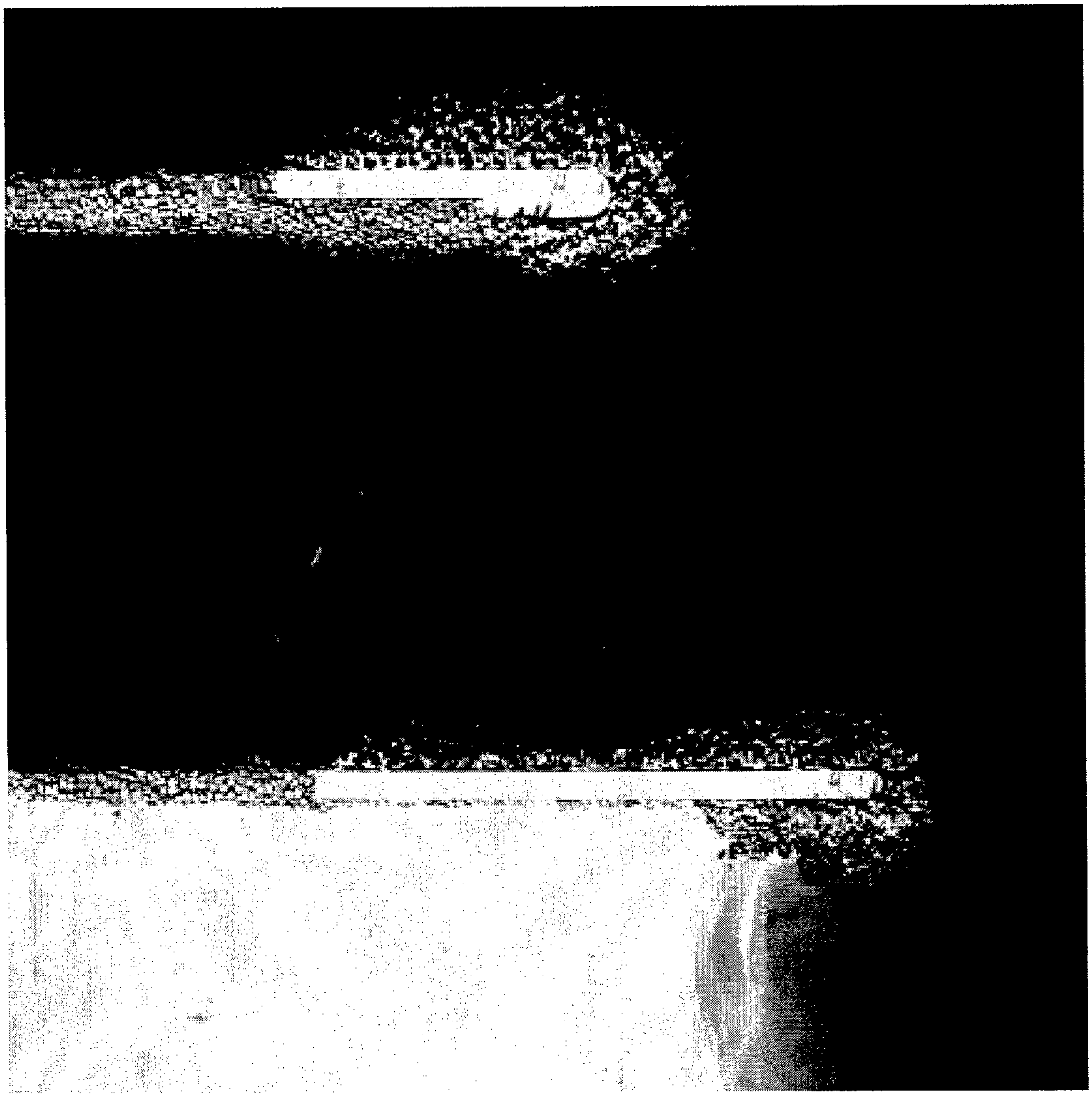

Figure 21. Stereo pair photograph for Manasquan Inlet jetties (middle photograph image)

locations are shown in Figures 23 and 24. Some of the data recorded relative to these broken/cracked dolos armor units are shown in Table 4. Of the eight broken/cracked dolos armor units observed, six were identified in the previous (1994) survey, and two (units 1 and 4 on the north jetty) were new breaks.

Considering the types of breaks, the majority (six) were shank-fluke breaks. There was one midshank break and one fluke-shank break. There were four angled breaks and four straight ones. Comparison of breakage to production data showed that no production group had an unusual amount of breakage. The distribution of broken/cracked dolosse indicated that seven of the eight units were concentrated around the seaward heads of the jetties, as shown in Figures 23 and 24. Views of typical broken/cracked dolos armor units on the Manasquan Inlet

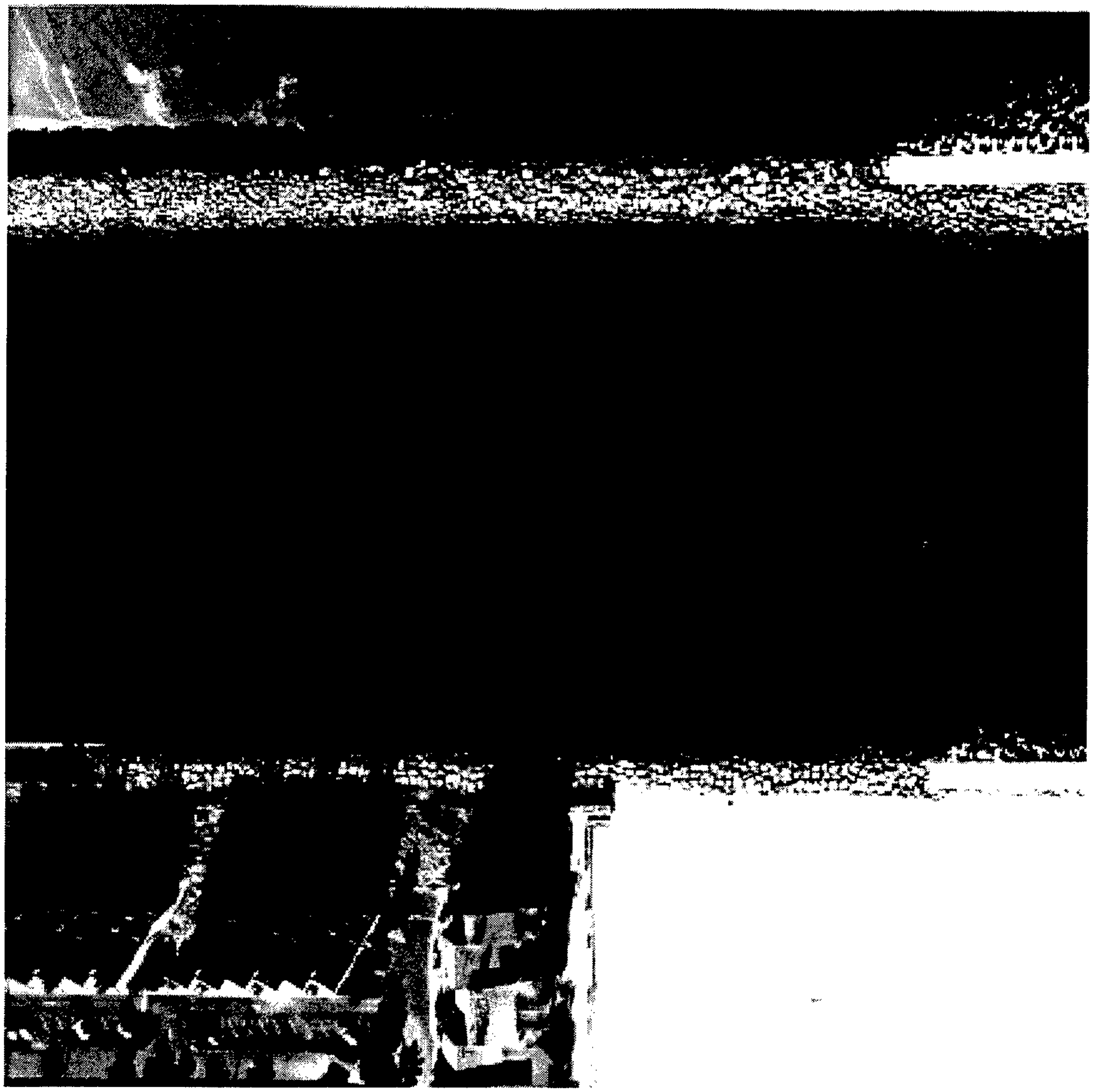

Figure 22. Stereo pair photograph for Manasquan Inlet jetties (landward photograph image)

jetties are shown in Figures 25-27. The detailed data obtained during the current survey (1998) will allow for an accurate indication of new breakage when the structures are revisited at some point in the future.

In general, typical reasons for dolos breakage often include the following: (a) stress patterns within the original cast dolosse, (b) handling and placement, (c) settling of the structure, stressing units within the breakwater, (d) wave-induced displacement, (e) wave-induced rocking and fatigue failure, (f) ice pressure and movement, and (g) impact from debris, other dolosse, and dolos fragments.

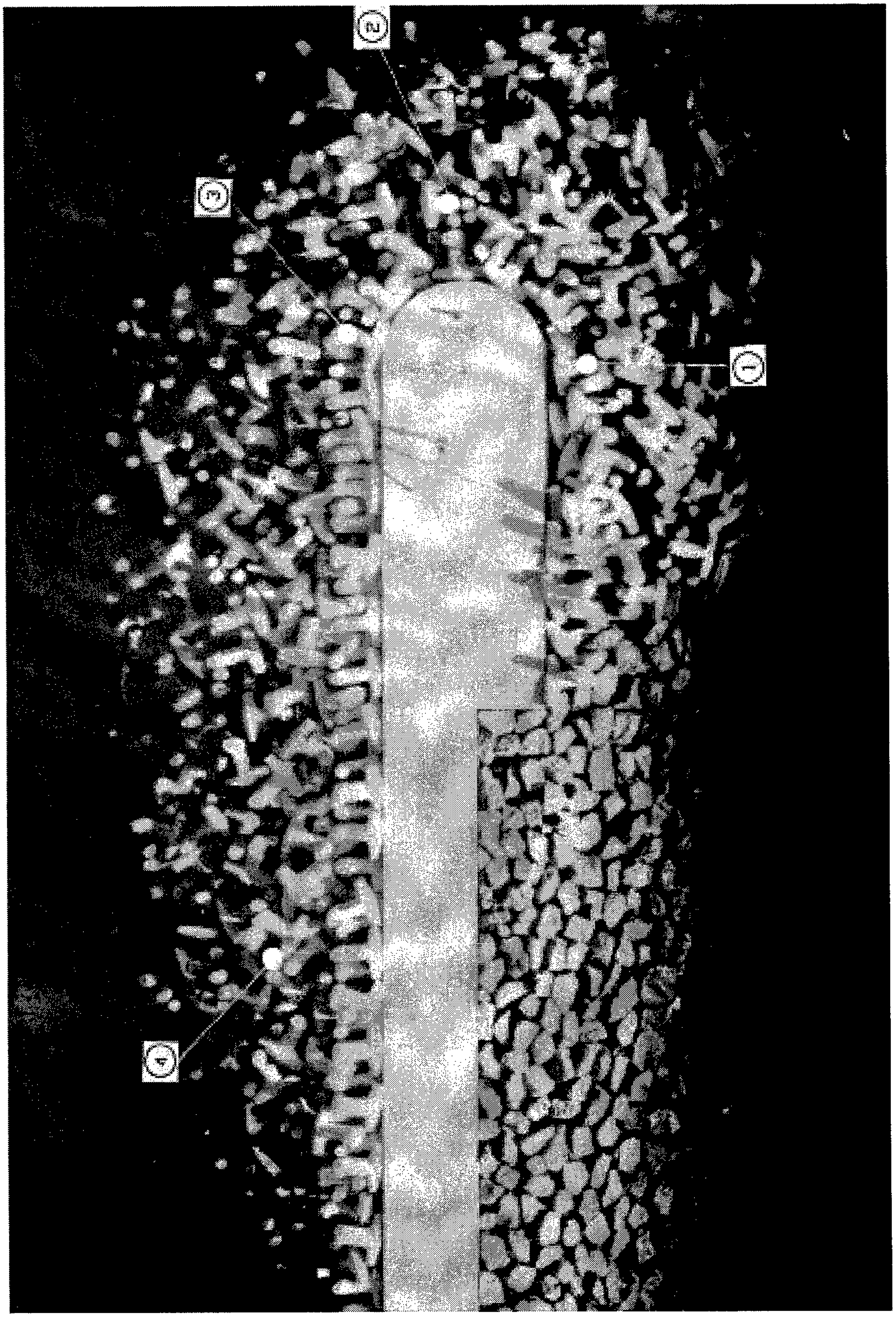

Figure 23. Approximate locations of broken/cracked dolos armor units on north jetty

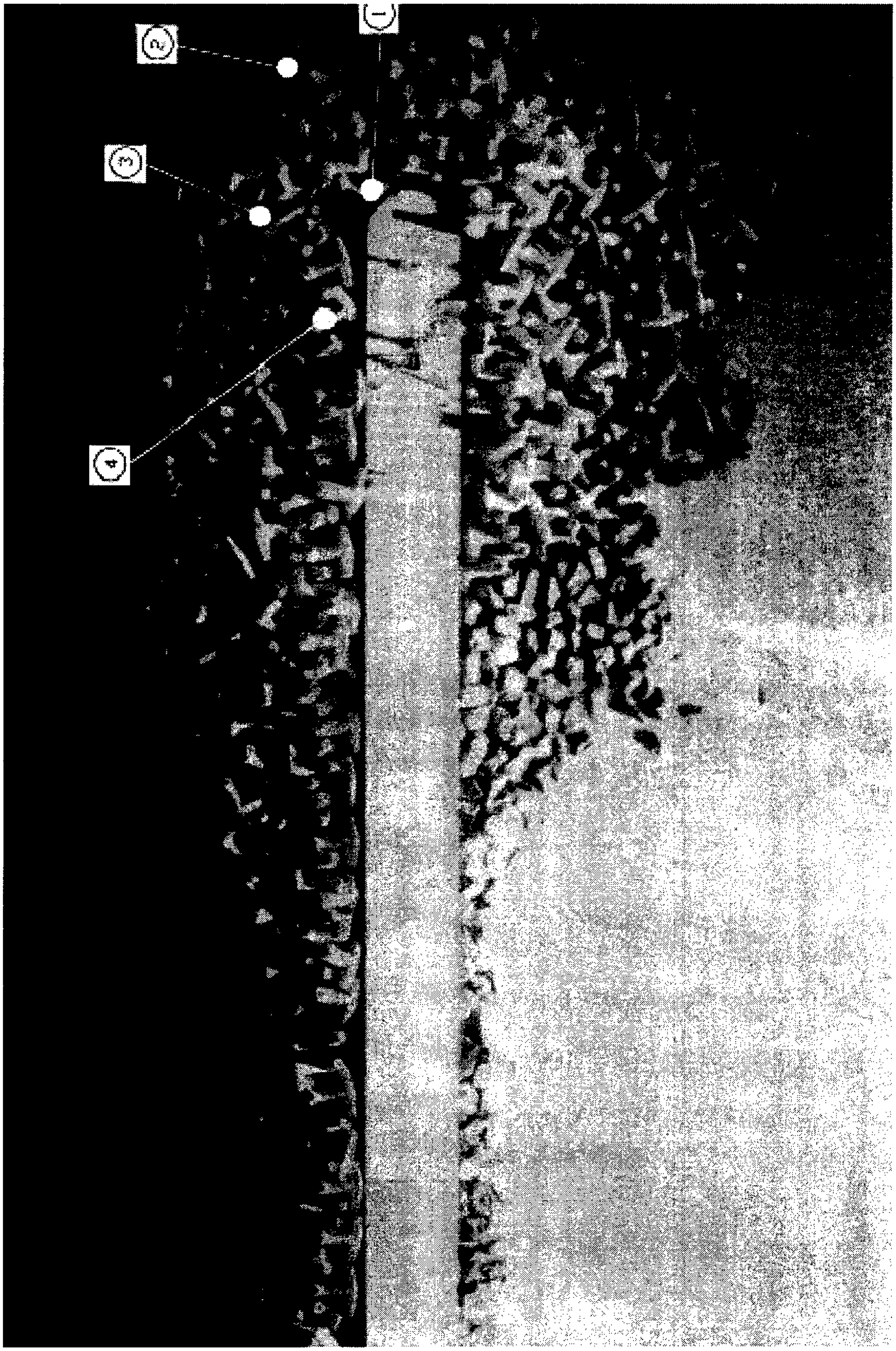

Figure 24. Approximate locations of broken/cracked dolos armor units on south jetty

Table 4 Broken Armor Unit Survey			
Unit No.	**Offset from Jetty Cap, m (ft)**	**Type of Break**	**Comments**
North Jetty			
1	3.1 (10)	Angled fluke-shank	Fluke chipped
2	5.2 (17)	Angled shank-fluke	Hairline crack
3	1.5 (5)	Straight shank-fluke	Hairline crack, fluke chipped underneath
4	7.9 (26)	Angled midshank	Rebar exposed
South Jetty			
1	1.1 (3.5)	Straight shank-fluke	Cracked through
2	11.4 (38)	Straight shank-fluke	Fluke broke off
3	10.1 (33)	Straight shank-fluke	Fluke only
4	1.5 (5)	Angled shank-fluke	Cracked through

Figure 25. Dolos with angled midshank break

Figure 26. Dolos with angled shank-fluke break

Comparison of Dolosse Armor Unit Movement Data

Initially, the horizontal and vertical positions of the 101 targeted dolosse distributed along the north and south jetties were evaluated for the 1998 and 1994 photogrammetric surveys. Horizontal positions and elevations of the targets, obtained from the stereo models, are shown in Tables 5 and 6 for the 1998 and 1994 surveys, respectively. Horizontal data are based on the New Jersey State Plane Coordinate System, and elevations are referenced to mean low water.

Displacements between the horizontal and vertical positions of the targets established on the north and south jetties are shown in Table 7 for the two surveys.

An analysis of movement data for the targeted dolosse on the north and south jetties between 1994 and 1998 revealed significantly less movement than detected during previous survey periods. Movement of the dolosse targets in the horizontal (northing and easting) directions ranged from 0 m (0 ft) to 0.54 m (1.76 ft), and vertical displacement ranged from 0 m (0 ft) to 0.07 m (0.22 ft). Only three target positions on the north jetty moved over 0.15 m (0.5 ft) in the horizontal direction. All other target positions on the north jetty moved 0.076 m

Figure 27. Dolos with straight shank-fluke crack

(0.25 ft) or less in the horizontal direction; all targets on the south jetty moved 0.064 m (0.21 ft) or less horizontally. In the vertical direction, target movement did not exceed 0.067 m (0.22 ft) on the north jetty and 0.064 m (0.21 ft) on the south jetty.

Between 1994 and 1998, the average movement of the targets on the north jetty was 0.061, 0.03, and 0.027 m (0.2, 0.1, and 0.09 ft) in the northing and easting horizontal directions and the vertical direction, respectively. On the south jetty, the average movement of the targets between 1994 and 1998 in the northing and easting horizontal directions and the vertical direction was 0.027, 0.015, and 0.027 m (0.09, 0.05, and 0.09 ft), respectively. This analysis indicates that movement of target positions on the north jetty in the northing and easting horizontal directions was slightly greater than the movement of units on the south jetty since 1994.

Horizontal displacement of the targets, in general, along the structure was in several directions with movement away from the jetty center lines for some units and toward the center line for others. Target movement also occurred parallel to the jetty center lines both in the shoreward and seaward directions. There was no dominance in these movement directions for targets on the jetties. The majority of the horizontal movements on both jetties was less than 0.03 m (0.1 ft). Vertical displacements of the targets on both jetties was minimal. Some targets

Table 5
Data Obtained from 1998 Photogrammetric Survey

Target	Easting	Northing	Elevation, m (ft)
North Jetty			
1	2177524.19	462578.14	5.85 (19.18)
2	2177527.84	462571.43	4.12 (13.53)
3	2177531.38	462569.32	4.33 (14.22)
4	2177538.42	462568.03	6.86 (19.71)
5	2177535.58	462557.93	4.20 (13.78)
6	2177442.92	462698.01	4.83 (15.85)
7	2177448.20	462700.86	4.13 (13.55)
8	2177451.52	462689.47	5.92 (19.43)
9	2177467.65	462677.04	5.96 (19.56)
10	2177481.12	462673.64	5.58 (18.32)
11	2177483.67	462668.41	5.99 (19.65)
13	2177496.17	462672.78	4.45 (14.60)
14	2177510.39	462683.77	3.80 (12.46)
15	2177524.76	462643.11	5.03 (16.50)
16	2177523.06	462647.72	4.75 (15.58)
17	2177532.69	462658.99	4.83 (15.84)
18	2177538.31	462636.76	4.05 (13.29)
19	2177554.77	462651.17	4.51 (14.79)
20	2177571.60	462643.46	4.54 (14.90)
21	2177578.35	462637.03	5.10 (16.74)
22	2177562.56	462616.32	5.05 (16.58)
23	2177564.10	462609.22	5.11 (16.76)
24	2177586.57	462632.92	4.30 (14.10)
25	2177582.48	462611.75	5.37 (17.63)
26	2177597.26	462609.32	4.67 (15.31)
27	2177603.68	462590.16	4.76 (15.63)
28	2177607.25	462588.35	5.12 (16.81)
29	2177620.72	462593.14	4.91 (16.11)
30	2177614.77	462579.77	5.67 (18.60)
31	2177613.80	462573.16	4.85 (15.92)
33	2177635.56	462564.53	4.48 (14.71)
34	2177618.53	462548.34	5.27 (17.29)

(Sheet 1 of 4)

Table 5 (Continued)			
Target	**Easting**	**Northing**	**Elevation, m (ft)**
North Jetty (continued)			
35	2177612.52	462543.89	5.34 (17.53)
36	2177622.51	462540.48	4.48 (14.71)
37	2177603.31	462534.48	5.04 (16.52)
38	2177606.46	462534.75	3.96 (13.00)
40	2177610.66	462520.11	4.02 (13.19)
43	2177589.46	462533.84	4.47 (14.68)
45	2177576.55	462536.51	3.61 (11.83)
46	2177568.16	462538.35	4.19 (13.76)
47	2177567.13	462546.51	4.42 (14.50)
49	2177554.96	462544.15	3.38 (11.10)
50	2177556.34	462551.49	4.22 (13.83)
51	2177549.10	462559.71	4.01 (13.14)
South Jetty			
1	2177453.50	462120.90	5.03 (16.51)
2	2177453.57	462114.70	4.75 (15.58)
3	2177457.91	462114.01	5.24 (17.20)
4	2177462.71	462106.60	4.99 (16.36)
5	2177453.94	462096.58	4.11 (11.80)
6	2177477.68	462103.09	4.95 (16.25)
7	2177473.32	462097.87	4.33 (14.20)
8	2177482.03	462097.21	5.36 (17.60)
9	2177501.98	462083.54	5.17 (14.85)
10	2177505.69	462077.79	4.88 (14.01)
11	2177513.96	462075.17	4.39 (14.39)
12	2177535.26	462081.32	4.10 (13.44)
13	2177538.51	462103.71	4.53 (14.85)
14	2177537.31	462112.74	3.98 (13.06)
15	2177530.86	462116.44	4.51 (14.80)
16	2177515.45	462124.86	4.32 (14.17)
17	2177516.06	462137.60	3.92 (12.86)
18	2177514.60	462139.89	4.66 (15.28)
19	2177498.35	462138.59	4.51 (14.80)
20	2177487.36	462142.86	5.52 (18.11)
			(Sheet 2 of 4)

Table 5 (Continued)			
Target	Easting	Northing	Elevation, m (ft)
South Jetty (continued)			
21	2177484.89	462148.59	4.15 (13.60)
22	2177479.35	462151.52	4.85 (15.92)
23	2177467.54	462150.97	4.63 (15.19)
24	2177467.29	462154.07	5.83 (19.14)
26	2177464.58	462163.21	5.22 (17.11)
27	2177449.18	462168.41	4.58 (15.02)
28	2177447.21	462171.07	4.75 (15.58)
29	2177438.11	462172.78	4.63 (15.20)
30	2177451.10	462185.83	4.61 (15.14)
31	2177448.42	462193.66	4.29 (14.07)
32	2177438.42	462179.30	4.30 (14.12)
33	2177433.66	462178.37	4.59 (15.06)
34	2177444.10	462198.81	2.38 (7.82)
35	2177415.65	462186.03	4.39 (14.41)
36	2177406.54	462200.62	4.26 (13.96)
37	2177400.12	462203.19	4.96 (16.27)
38	2177385.06	462214.99	4.08 (13.37)
39	2177366.04	462226.61	4.88 (16.01)
41	2177348.34	462240.06	4.45 (14.61)
42	2177333.24	462251.97	4.68 (15.35)
43	2177328.53	462252.74	4.27 (14.01)
44	2177311.52	462261.63	4.57 (14.98)
45	2177299.33	462269.01	5.64 (18.52)
46	2177294.23	462276.74	5.49 (18.01)
47	2177277.54	462280.58	5.31 (17.43)
48	2177271.10	462286.78	5.14 (16.87)
49	2177268.96	462291.38	5.07 (16.64)
50	2177275.55	462303.38	3.61 (11.86)
52	2177261.88	462312.91	4.66 (15.28)
53	2177254.48	462327.37	2.86 (9.380
54	2177242.72	462327.10	4.88 (16.00)
55	2177241.29	462328.96	4.16 (13.64)
			(Sheet 3 of 4)

Table 5 (Concluded)			
Target	Easting	Northing	Elevation, m (ft)
South Jetty (continued)			
56	2177231.46	462314.69	6.09 (19.99)
57	2177227.63	462323.25	5.43 (17.82)
58	2177222.17	462326.94	4.20 (13.77)
59	2177218.84	462326.78	5.04 (16.54)
60	2177212.47	462326.46	5.21 (17.09)
			(Sheet 4 of 4)

moved upward slightly and some slightly subsided. The majority of elevation changes was less than 0.03 m (0.1 ft) on both structures.

Comparisons of armor unit movement data to this point have included only target data and not movement of the entire armor unit. Therefore, to assess the motions of the entire armor unit, outlines of each targeted dolos were extracted from the stereo models and compared for the 1994 and 1998 surveys. These comparisons depicted horizontal positions, and actual distances moved were scaled off the photogrammetric maps that were prepared. To determine vertical movements of the targeted armor units, additional elevations were obtained from the stereo models at one or two additional points on the dolosse (points other than the established targets). An example of the position of a targeted armor unit and additional elevations for the two surveys is shown in Figure 28.

Evaluation of horizontal motions of the targeted dolosse indicated that, for the majority of units, movement was relatively uniform. The entire unit tended to move in the same direction (linear as opposed to rotational). Forty-eight percent of the targeted armor units on the north jetty and 20 percent of those on the south jetty slightly rotated in either a clockwise or counterclockwise direction. Considering all the rotated armor units on both structures, there was not a dominance of clockwise or counterclockwise rotation observed. However, the majority of the armor units that rotated on the north jetty tended to move in a clockwise direction, while those on the south jetty tended to rotate in counterclockwise directions. In general, randomly placed dolosse tend to be oriented with one fluke positioned near vertical and the other lying near horizontal. In some cases, the vertical fluke is positioned nearer to the jetty center line and the horizontal portion downslope farther from the jetty center line. In other instances, the horizontal fluke is placed closer to the center line with the vertical fluke farther downslope. Of the targeted armor units that rotated on the jetties, the majority consisted of those placed with the vertical fluke farther downslope and the horizontal fluke closer to the jetty center line. Considering movements of the entire armor unit, maximum horizontal displacements for any point on the targeted dolosse on the north and south jetties were approximately 0.7 m (2.3 ft) and 0.091 m (0.3 ft), respectively, between 1994 and 1998. The averages of the maximum horizontal movements for the targeted dolosse during this time frame

Table 6
Data Obtained from 1994 Photogrammetric Survey

Target	Easting	Northing	Elevations, m (ft)
North Jetty			
1	2177524.06	462578.70	5.87 (19.25)
2	2177527.78	462571.58	4.15 (13.62)
3	2177531.16	462569.54	4.36 (14.32)
4	2177537.60	462568.24	5.99 (19.66)
5	2177535.33	462558.13	4.22 (13.84)
6	2177442.80	462698.08	4.82 (15.82)
7	2177448.16	462700.93	4.11 (13.49)
8	2177451.38	462689.58	5.91 (19.38)
9	2177467.43	462677.13	5.96 (19.56)
10	2177481.04	462673.64	5.60 (18.38)
11	2177483.64	462668.58	6.00 (19.67)
13	2177496.00	462672.88	4.51 (14.80)
14	2177510.46	462683.86	3.77 (12.37)
15	2177524.66	462643.13	5.03 (16.50)
16	2177523.04	462647.83	4.71 (15.46)
17	2177532.70	462659.08	4.80 (15.74)
18	2177538.26	462636.86	4.02 (13.19)
19	2177554.74	462651.20	4.48 (14.71)
20	2177571.44	462643.60	4.51 (14.80)
21	2177578.28	462637.13	5.09 (16.70)
22	2177562.50	462616.48	5.01 (16.45)
23	2177564.00	462609.33	5.07 (16.64)
24	2177586.38	462632.96	4.28 (14.05)
25	2177582.38	462611.84	5.34 (17.52)
26	2177597.16	462609.50	4.67 (15.31)
27	2177603.54	462590.18	4.79 (15.70)
28	2177607.23	462588.38	5.09 (16.70)
29	2177620.58	462593.14	4.90 (16.07)
30	2177614.70	462579.84	5.65 (18.55)

(Sheet 1 of 3)

Table 6 (Continued)			
Target	**Easting**	**Northing**	**Elevations, m (ft)**
North Jetty (continued)			
31	2177613.70	462573.08	4.85 (15.92)
33	2177635.54	462564.56	4.43 (14.52)
34	2177618.44	462548.40	5.23 (17.17)
35	2177612.56	462544.03	5.29 (17.37)
36	2177622.38	462540.56	4.43 (14.52)
37	2177603.24	462534.58	5.01 (16.44)
38	2177606.38	462534.78	3.90 (12.78)
40	2177610.53	462520.30	3.96 (12.99)
43	2177587.70	462532.43	4.52 (14.84)
45	2177576.36	462536.56	3.56 (11.68)
46	2177568.14	462538.58	4.19 (13.76)
47	2177567.04	462546.68	4.40 (14.45)
49	2177554.86	462544.14	3.35 (10.99)
50	2177556.26	462551.64	4.22 (13.86)
51	2177549.04	462559.94	3.97 (13.01)
South Jetty			
1	2177453.30	462120.83	5.03 (16.51)
2	2177453.51	462114.76	4.74 (15.55)
3	2177457.86	462113.99	5.21 (17.08)
4	2177462.66	462106.60	4.96 (16.26)
5	2177453.84	462096.59	3.56 (11.68)
6	2177477.66	462103.16	4.92 (16.14)
7	2177473.34	462097.89	4.31 (14.14)
8	2177481.94	462097.19	5.32 (17.45)
9	2177501.76	462083.61	4.50 (14.77)
10	2177505.74	462077.81	4.24 (13.91)
11	2177513.91	462075.31	4.35 (14.28)
12	2177535.21	462081.34	4.09 (13.43)
13	2177538.44	462103.69	4.56 (14.95)
14	2177537.24	462112.84	4.01 (13.15)
15	2177530.90	462116.60	4.54 (14.89)
16	2177515.36	462124.84	4.29 (14.08)
17	2177516.01	462137.64	3.91 (12.84)
18	2177514.44	462139.91	4.64 (15.23)
19	2177498.40	462138.60	4.48 (14.69)
			(Sheet 2 of 3)

Table 6 (Concluded)			
Target	**Easting**	**Northing**	**Elevations, m (ft)**
	South Jetty (Continued)		
20	2177487.39	462142.91	5.51 (18.08)
21	2177484.70	462148.60	4.15 (13.61)
22	2177479.24	462151.51	4.82 (15.81)
23	2177467.40	462150.94	4.61 (15.11)
24	2177467.21	462153.99	5.81 (19.05)
26	2177464.50	462163.24	5.20 (17.07)
27	2177449.11	462168.41	4.56 (14.96)
28	2177447.11	462171.20	4.72 (15.47)
29	2177438.14	462172.76	4.63 (15.19)
30	2177450.94	462185.81	4.58 (15.03)
31	2177448.30	462193.71	4.30 (14.11)
32	2177438.44	462179.30	4.27 (14.00)
33	2177433.64	462178.40	4.57 (14.99)
34	2177444.08	462198.60	2.38 (7.80)
35	2177415.56	462186.10	4.35 (14.26)
36	2177406.34	462200.63	4.20 (13.79)
37	2177400.03	462203.18	4.92 (16.15)
38	2177384.88	462215.03	4.05 (13.30)
39	2177365.96	462226.70	4.83 (15.86)
41	2177348.26	462240.06	4.40 (14.45)
42	2177333.20	462252.00	4.69 (15.38)
43	2177328.40	462252.83	4.26 (14.00)
44	2177311.38	462261.64	4.58 (15.01)
45	2177299.26	462268.80	5.71 (18.73)
46	2177294.03	462276.73	5.48 (17.98)
47	2177277.40	462280.64	5.35 (17.54)
48	2177271.06	462286.74	5.07 (16.64)
49	2177270.43	462290.20	5.17 (16.95)
50	2177275.43	462303.44	3.65 (11.97)
52	2177261.78	462312.96	4.68 (15.37)
53	2177254.34	462327.46	2.89 (9.48)
54	2177242.60	462327.13	4.92 (16.15)
55	2177241.23	462329.06	4.20 (13.77)
56	2177231.34	462314.73	6.12 (20.09)
57	2177227.53	462323.38	5.45 (17.89)
58	2177221.98	462327.06	4.23 (13.88)
59	2177218.68	462326.80	5.08 (16.67)
60	2177212.36	462326.50	5.22 (17.13)
			(Sheet 3 of 3)

Table 7
Differences in Target Positions for 1994 and 1998 Surveys

Target	Easting	Northing	Elevation
North Jetty			
1	0.04 (0.13)	0.17 (0.56)	0.02 (0.07)
2	0.02 (0.06)	0.05 (0.15)	0.03 (0.09)
3	0.07 (0.22)	0.07 (0.22)	0.03 (0.10)
4	0.25 (0.82)	0.06 (0.21)	0.02 (0.05)
5	0.08 (0.25)	0.06 (0.20)	0.02 (0.06)
6	0.04 (0.12)	0.02 (0.07)	0.01 (0.03)
7	0.01 (0.04)	0.02 (0.07)	0.02 (0.06)
8	0.04 (0.14)	0.03 (0.11)	0.02 (0.05)
9	0.07 (0.22)	0.03 (0.09)	0 (0)
10	0.02 (0.08)	0 (0)	0.02 (0.06)
11	0.01 (0.03)	0.05 (0.17)	0.01 (0.02)
13	0.05 (0.17)	0.03 (0.10)	0.06 (0.20)
14	0.02 (0.07)	0.03 (0.09)	0.03 (0.09)
15	0.03 (0.10)	0.01 (0.02)	0 (0)
16	0.01 (0.02)	0.03 (0.11)	0.04 (0.12)
17	0.01 (0.01)	0.03 (0.09)	0.03 (0.10)
18	0.02 (0.05)	0.03 (0.10)	0.03 (0.10)
19	0.01 (0.03)	0.01 (0.03)	0.02 (0.08)
20	0.05 (0.16)	0.04 (0.14)	0.03 (0.10)
21	0.02 (0.07)	0.03 (0.10)	0.01 (0.04)
22	0.02 (0.06)	0.05 (0.16)	0.04 (0.13)
23	0.03 (0.10)	0.03 (0.11)	0.04 (0.12)
24	0.06 (0.19)	0.01 (0.04)	0.02 (0.05)
25	0.03 (0.10)	0.03 (0.09)	0.03 (0.11)
26	0.03 (0.10)	0.05 (0.18)	0 (0)
27	0.04 (0.14)	0.01 (0.02)	0.02 (0.07)
28	0.01 (0.02)	0.01 (0.03)	0.03 (0.11)
29	0.04 (0.14)	0 (0)	0.01 (0.04)
30	0.02 (0.07)	0.02 (0.07)	0.02 (0.05)
31	0.03 (0.10)	0.02 (0.08)	0 (0)
33	0.01 (0.02)	0.01 (0.03)	0.06 (0.19)
34	0.03 (0.09)	0.02 (0.06)	0.04 (0.12)

(Sheet 1 of 4)

Table 7 (Continued)			
Target	Easting	Northing	Elevation
North Jetty (continued)			
35	0.01 (0.04)	0.04 (0.14)	0.05 (0.16)
36	0.04 (0.13)	0.02 (0.08)	0.06 (0.19)
37	0.02 (0.07)	0.03 (0.10)	0.02 (0.08)
38	0.02 (0.08)	0.01 (0.03)	0.07 (0.22)
40	0.04 (0.13)	0.06 (0.19)	0.07 (0.20)
43	0.54 (1.76)	0.43 (1.41)	0.05 (0.16)
45	0.06 (0.19)	0.02 (0.05)	0.05 (0.15)
46	0.01 (0.02)	0.07 (0.23)	0 (0)
47	0.03 (0.09)	0.05 (0.17)	0.02 (0.05)
49	0.03 (0.10)	0.01 (0.01)	0.03 (0.11)
50	0.02 (0.08)	0.05 (0.15)	0.01 (0.03)
51	0.02 (0.06)	0.07 (0.23)	0.04 (0.13)
South Jetty			
1	0.061 (0.20)	0.006 (0.02)	0.046 (0.15)
2	0.018 (0.06)	0.018 (0.06)	0.009 (0.03)
3	0.015 (0.05)	0.006 (0.02)	0.037 (0.12)
4	0.015 (0.05)	0 (0)	0.030 (0.10)
5	0.030 (0.10)	0.003 (0.01)	0.037 (0.12)
6	0.006 (0.02)	0.021 (0.07)	0.034 (0.11)
7	0.006 (0.02)	0.006 (0.02)	0.018 (0.06)
8	0.027 (0.09)	0.006 (0.02)	0.046 (0.15)
9	0.006 (0.02)	0.021 (0.07)	0.024 (0.08)
10	0.015 (0.05)	0.006 (0.02)	0.030 (0.10)
11	0.015 (0.05)	0.043 (0.14)	0.034 (0.11)
12	0.015 (0.05)	0.006 (0.02)	0.003 (0.01)
13	0.021 (0.07)	0.006 (0.02)	0.030 (0.10)
14	0.021 (0.07)	0.030 (0.10)	0.027 (0.09)
15	0.012 (0.04)	0.049 (0.16)	0.027 (0.09)
16	0.027 (0.09)	0.006 (0.02)	0.027 (0.09)
17	0.015 (0.05)	0.012 (0.04)	0.006 (0.02)
18	0.049 (0.16)	0.006 (0.02)	0.015 (0.05)
19	0.015 (0.05)	0.003 (0.01)	0.034 (0.11)
			(Sheet 2 of 4)

Table 7 (Continued)			
Target	Easting	Northing	Elevation
South Jetty (continued)			
20	0.009 (0.03)	0.015 (0.05)	0.009 (0.03)
21	0.058 (0.19)	0.003 (0.01)	0.003 (0.01)
22	0.034 (0.11)	0.003 (0.01)	0.034 (0.11)
23	0.043 (0.14)	0.009 (0.03)	0.024 (0.08)
24	0.024 (0.08)	0.024 (0.08)	0.027 (0.09)
26	0.024 (0.08)	0.009 (0.03)	0.012 (0.04)
27	0.021 (0.07)	0 (0)	0.018 (0.06)
28	0.030 (0.10)	0.040 (0.13)	0.034 (0.11)
29	0.009 (0.03)	0.006 (0.02)	0.003 (0.01)
30	0.049 (0.16)	0.006 (0.02)	0.034 (0.11)
31	0.037 (0.12)	0.015 (0.05)	0.012 (0.04)
32	0.006 (0.02)	0 (0)	0.037 (0.12)
33	0.006 (0.02)	0.009 (0.03)	0.021 (0.07)
34	0.006 (0.02)	0.064 (0.21)	0.006 (0.02)
35	0.027 (0.09)	0.021 (0.07)	0.046 (0.15)
36	0.061 (0.20)	0.003 (0.01)	0.052 (0.17)
37	0.027 (0.09)	0.003 (0.01)	0.037 (0.12)
38	0.055 (0.18)	0.012 (0.04)	0.021 (0.07)
39	0.024 (0.08)	0.027 (0.09)	0.046 (0.15)
41	0.024 (0.08)	0 (0)	0.049 (0.16)
42	0.012 (0.04)	0.009 (0.03)	0.009 (0.03)
43	0.040 (0.13)	0.027 (0.09)	0.003 (0.01)
44	0.043 (0.14)	0.003 (0.01)	0.009 (0.03)
45	0.021 (0.07)	0.064 (0.21)	0.064 (0.21)
46	0.061 (0.20)	0.003 (0.01)	0.009 (0.03)
47	0.043 (0.14)	0.018 (0.06)	0.034 (0.11)
48	0.012 (0.04)	0.012 (0.04)	0.070 (0.23)
49	0.043 (0.14)	0.009 (0.03)	0.094 (0.31)
50	0.037 (0.12)	0.018 (0.06)	0.034 (0.11)
52	0.030 (0.10)	0.015 (0.05)	0.027 (0.09)
53	0.043 (0.14)	0.027 (0.09)	0.030 (0.10)
54	0.037 (0.12)	0.009 (0.03)	0.046 (0.15)
55	0.018 (0.06)	0.030 (0.10)	0.040 (0.13)
			(Sheet 3 of 4)

Table 7 (Concluded)			
Target	Easting	Northing	Elevation
South Jetty (continued)			
56	0.037 (0.12)	0.012 (0.04)	0.030 (0.10)
57	0.030 (0.10)	0.040 (0.13)	0.021 (0.07)
58	0.056 (0.19)	0.037 (0.12)	0.034 (0.11)
59	0.049 (0.16)	0.006 (0.02)	0.040 (0.13)
60	0.034 (0.11)	0.012 (0.04)	0.012 (0.04)
			(Sheet 4 of 4)

were 0.085 m (0.28 ft) and 0.052 m (0.17 ft), respectively, for the north and south jetties. Sixty-four percent of the targeted units on the north jetty and 79 percent of those targeted on the south jetty had maximum horizontal movements of 0.061 m (0.2 ft) or less at any point on the targeted dolosse.

Evaluation of the vertical motions of the targeted dolosse revealed that some units moved upward and some units subsided. A comparison of the vertical data between 1994 and 1998 indicated the average change in elevation of all points on the targeted units was 0.061 m (0.2 ft) and 0.052 m (0.17 ft) for the north and south jetties, respectively. The maximum vertical displacement for any point on a targeted dolos on the north jetty was 0.3 m (1.0 ft), and the maximum displacement for any point on a targeted dolos on the south jetty was 0.37 m (1.2 ft). Considering all values obtained for the targeted units, 32 percent of the elevation changes on the north jetty and 56 percent on the south jetty were 0.03 m (0.1 ft) or less.

In addition to the targeted armor units, additional (nontargeted) dolosse were selected on the north and south jetties for comparison of movement data between the 1994 and 1998 surveys. The locations of these additional armor units are shown in Figures 29 and 30. Thirty-three dolosse on the north and 29 on the south jetty were selected. Outlines of these additional dolosse, as well as elevations at two or three points on each unit, were obtained from the stereo models for the two surveys and compared on photogrammetric maps to determine horizontal and vertical motions, similar to the procedures used on the targeted units.

Evaluation of the horizontal motions of the additional dolosse indicated that movement was relatively uniform for over half of the armor units, in that the entire unit tended to move in the same direction (nonrotational movement). Forty-five percent of the dolosse on the north jetty and 32 percent of those on the south jetty slightly rotated in either a clockwise or counterclockwise direction. Considering the rotated armor units, there was a dominance of clockwise rotation on the north jetty, and counterclockwise rotation was dominate on the south jetty. In general, of the additional (nontargeted) armor units analyzed that

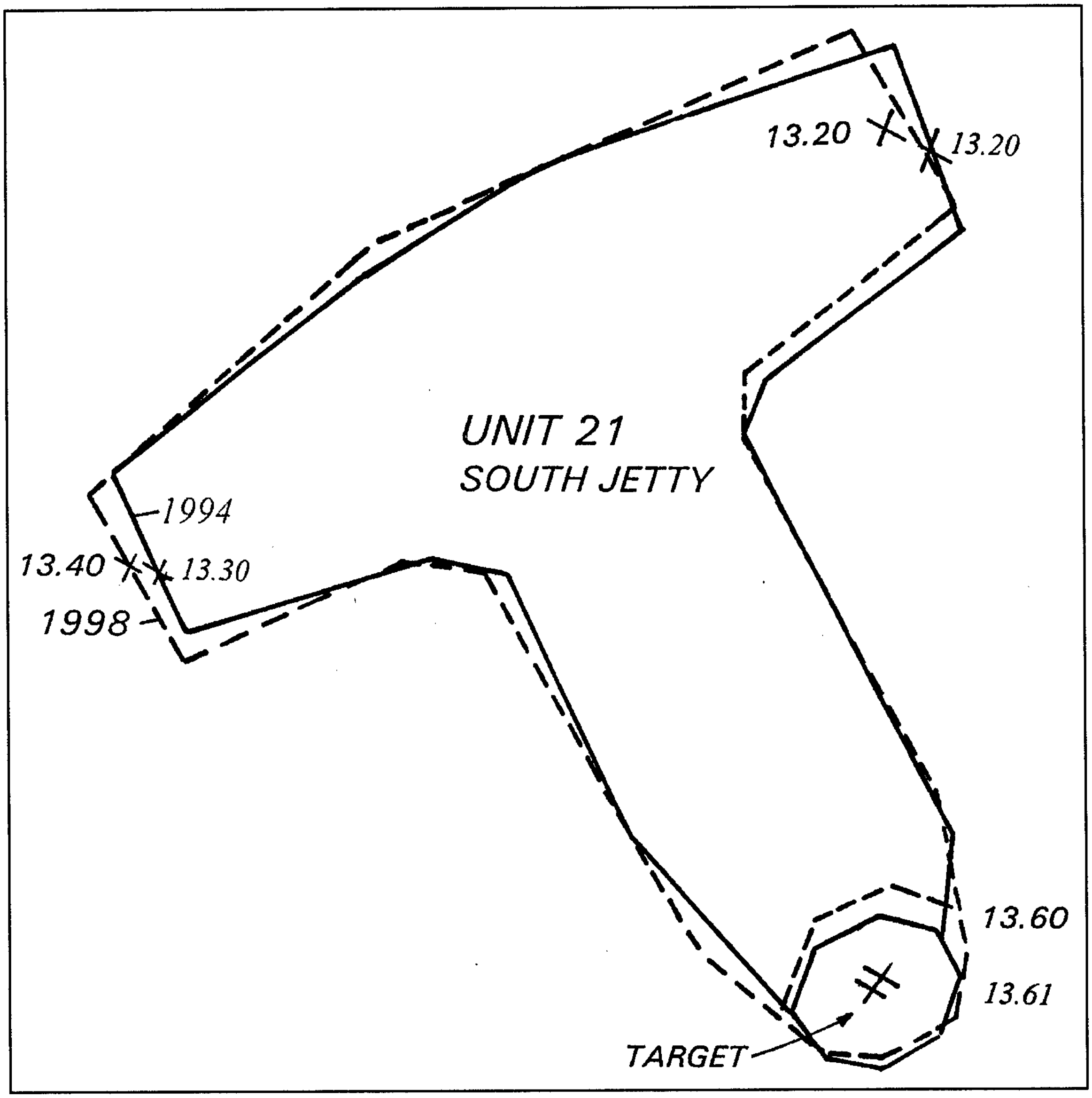

Figure 28. Example of horizontal position of a target dolosse armor unit and additional elevations obtained for 1994 and 1998 photogrammetric surveys

rotated on the jetties, the majority consisted of those oriented with the vertical fluke farther downslope and the horizontal fluke closer to the jetty center line. Between 1994 and 1998, maximum horizontal displacements for any point on the additional selected armor units were 0.122 m (0.4 ft) on both the north and south jetties. The averages of the maximum horizontal movements of the additional selected dolosse, between 1994 and 1998, were 0.043 m (0.14 ft) and 0.064 m (0.21 ft) for the north and south jetties, respectively. Sixty-six percent of the units on the north jetty and 55 percent of those on the south jetty had maximum horizontal movements of 0.061 m (0.21 ft) or less at any point on the additional selected (nontargeted) dolosse. In general, based on the photogrammetric

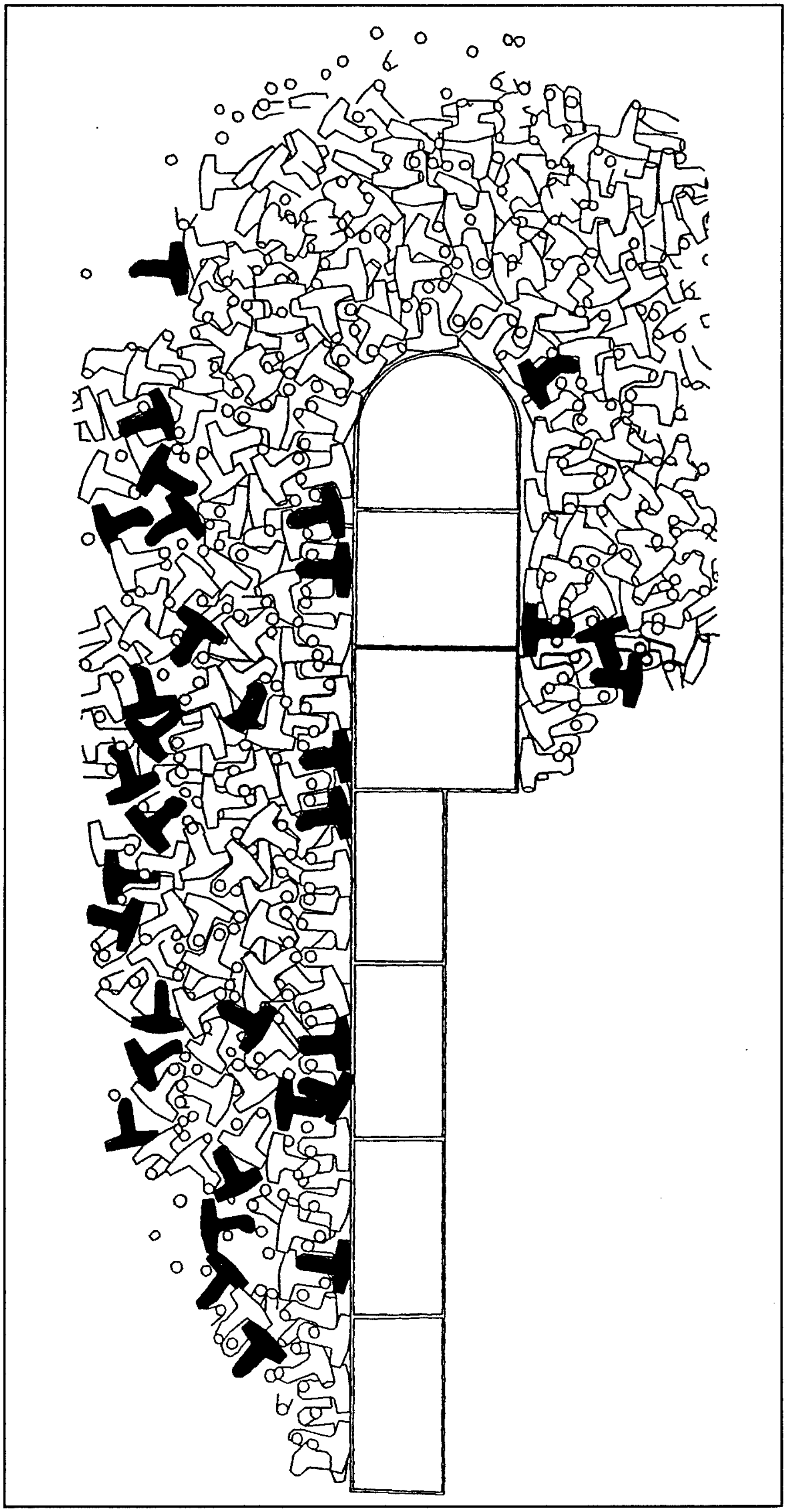

Figure 29. Nontargeted dolosse armor units selected for analysis on north jetty

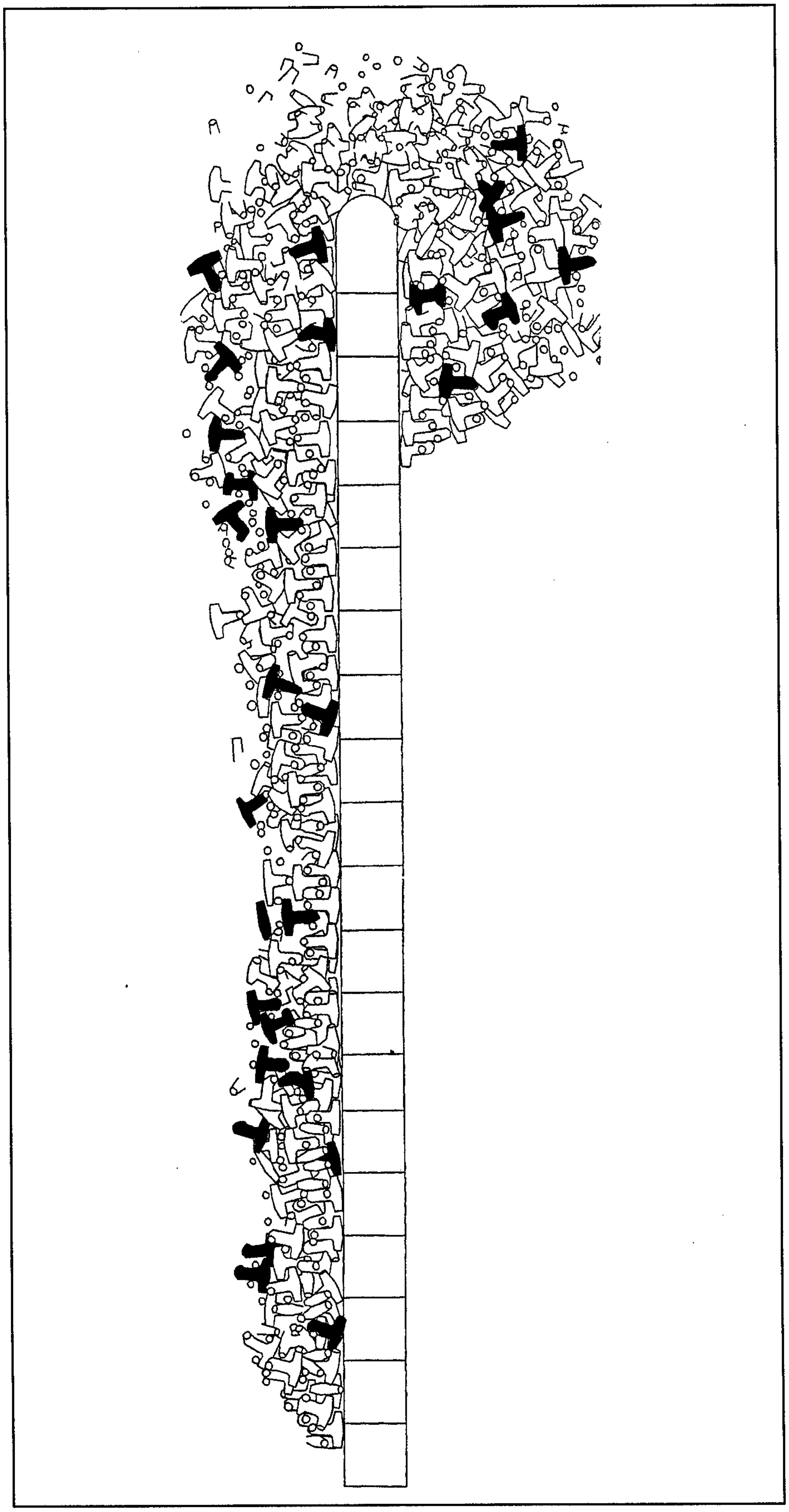

Figure 30. Nontargeted dolosse armor units selected for analysis on south jetty

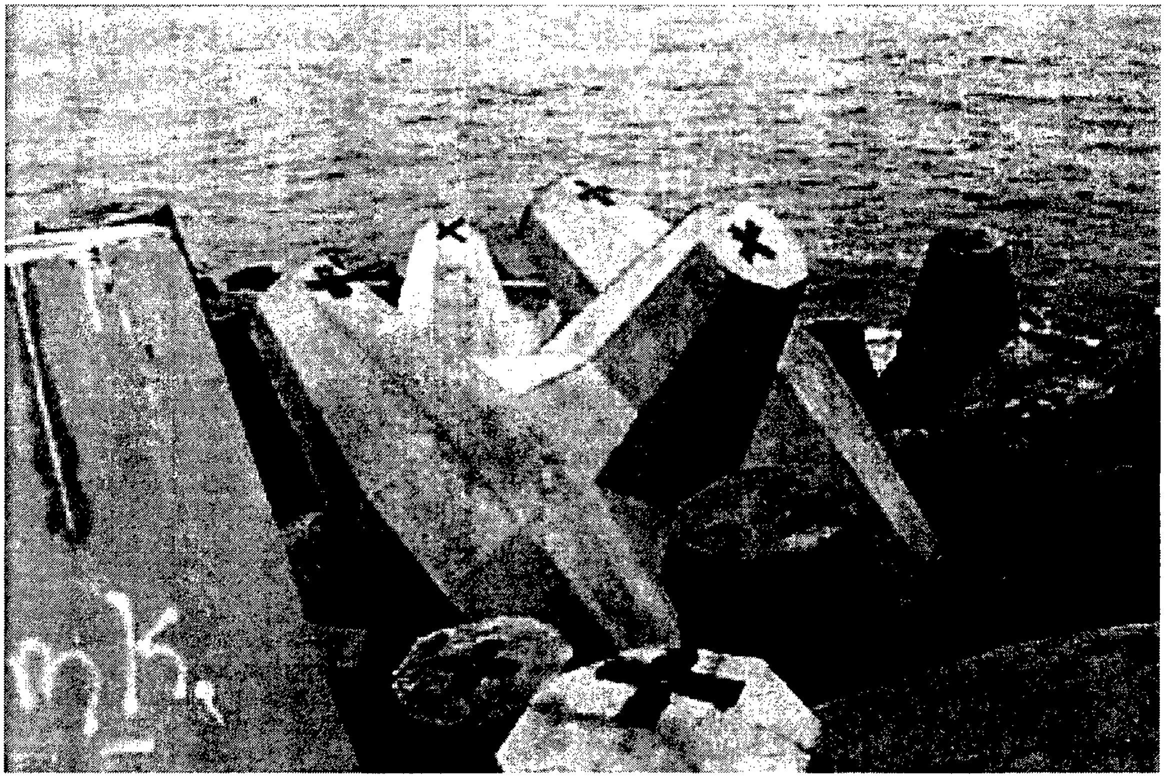

Figure 31. View of a CORE-LOC with multiple targets

analysis, horizontal displacements for the nontargeted armor units were similar to those obtained for the targeted units.

Evaluation of the vertical motions of the additional dolosse revealed that some units moved upward and some subsided. Comparisons of the vertical data for the nontargeted units indicated average displacement of 0.064 m (0.21 ft) and 0.067 m (0.22 ft), respectively, for the north and south jetties. The maximum vertical displacement for any point on a dolos was 0.27 m (0.9 ft) on both the north and south jetties. Considering all values obtained for the nontargeted units, 50 percent of the elevation changes were 0.03 m (0.1 ft) or less on both structures.

Examination of the dolosse armor unit positions for the 1994-1998 period revealed significantly less movement than obtained during previous survey periods. However, the more significant movement in previous surveys occurred around the heads of the jetties. During the 1997 rehabilitation, CORE-LOCs were placed around the jetty heads. Dolosse were covered and/or repositioned during this process. Therefore, no correlation in movement could be made for armor units in areas where the more significant movement occurred previously. In addition, the dolosse have been subjected to their environment for about 15 years and experienced several storm wave events. This has resulted in the armor units being shaken down. They have settled into the structure, which increases their stability. During the 1994-1998 monitoring period, several storm events occurred. These were generally northeasters that occurred in December

1994, February 1995, March 1995, November 1995, November 1997, January 1998, and February 1998. The January and February 1998 storms were the most severe and resulted in widespread beach erosion and coastal flooding along the New Jersey and Delaware coastlines.

Positions of CORE-LOC Armor Unit Targets

Initial data were obtained for the CORE-LOC armor units recently installed on the heads of the north and south jetties through photogrammetric analysis. Dependent upon the position of the CORE-LOCs, one to three targets were established on each unit. A view of a CORE-LOC armor unit with three targets is shown in Figure 31. The northing and easting horizontal positions and the elevations of the CORE-LOC targets are presented in Table 8. These data establish a base from which to evaluate armor unit movement during future surveys.

Table 8
CORE-LOC Data from 1998 Photogrammetric Survey

Target	Easting	Northing	Elevation, m (ft)
North Jetty			
1A	2177558.69	462533.35	3.90 (12.81)
1B	2177563.66	462538.53	3.58 (11.75)
1C	2177565.77	462532.32	3.18 (10.42)
2A	2177576.03	462531.64	3.83 (12.55)
2B	2177579.93	462527.68	4.87 (15.99)
2C	2177580.82	462534.30	4.91 (16.11)
3A	2177609.65	462525.87	4.72 (15.50)
3B	2177610.86	462532.29	4.32 (14.18)
3C	2177615.96	462528.28	5.30 (17.40)
4A	2177617.20	462520.27	3.53 (11.59)
4B	2177622.94	462523.55	3.54 (11.63)
5A	2177625.28	462517.19	3.51 (11.50)
5B	2177625.43	462523.73	3.07 (10.07)
5C	2177630.22	462521.17	4.29 (14.06)
6A	2177629.14	462509.35	3.25 (10.67)
6B	2177635.53	462509.57	3.87 (12.70)
7A	2177640.01	462509.13	3.26 (10.70)
8A	2177623.54	462529.32	3.34 (10.96)
8B	2177628.82	462530.08	4.76 (15.63)
8C	2177631.69	462524.88	3.48 (11.41)
9A	2177642.93	462534.54	4.04 (13.24)
9B	2177648.66	462531.25	3.72 (12.22)
9C	2177649.16	462537.50	4.55 (14.93)
10A	2177644.59	462545.25	4.54 (14.89)
10B	2177645.73	462551.54	4.12 (13.52)
10C	2177650.50	462548.07	4.93 (16.17)
11A	2177642.73	462561.41	4.66 (15.30)
11B	2177643.47	462554.25	4.84 (15.88)
11C	2177648.90	462559.01	4.90 (16.07)
12A	2177644.06	462565.26	3.40 (11.45)
12B	2177649.70	462568.72	3.69 (12.11)
12C	2177650.04	462561.66	3.74 (12.26)
13A	2177644.96	462573.55	4.18 (13.70)
13B	2177646.39	462580.11	4.06 (13.32)
13C	2177649.97	462575.86	3.34 (10.97)
14A	2177634.72	462574.25	4.64 (15.23)
14B	2177636.20	462568.81	3.47 (11.37)
14C	2177640.66	462576.04	3.64 (11.95)
15A	2177633.13	462592.41	3.93 (12.88)
15B	2177633.45	462599.68	3.91 (12.83)
15C	2177639.22	462596.09	3.71 (12.17)
16A	2177623.07	462589.20	4.62 (15.17)
16B	2177626.68	462583.03	4.97 (16.30)
16C	2177629.67	462589.61	4.80 (15.76)

(Continued)

Table 8 (Concluded)			
Target	**Easting**	**Northing**	**Elevation, m (ft)**
		South Jetty	
1A	2177516.69	462087.09	5.69 (18.67)
1B	2177521.43	462082.31	5.86 (19.22)
2A	2177520.96	462063.17	5.62 (18.44)
3A	2177515.15	462053.54	4.35 (14.28)
4A	2177525.04	462062.13	3.93 (12.90)
4B	2177530.62	462058.70	3.96 (12.98)
5A	2177524.38	462064.59	5.08 (16.67)
5B	2177524.83	462058.68	4.10 (13.44)
5C	2177532.19	462062.09	4.81 (15.77)
6A	2177540.41	462061.18	4.40 (14.42)
7A	2177534.97	462072.87	5.18 (17.01)
8A	2177549.09	462070.70	3.62 (11.89)
9A	2177540.64	462076.15	5.20 (17.07)
9B	2177544.55	462081.58	5.11 (16.76)
10A	2177554.67	462077.63	3.80 (12.46)
10B	2177556.05	462071.40	3.11 (10.20)
11A	2177562.41	462093.38	3.50 (11.49)
12A	2177547.02	462104.64	4.42 (14.50)
12B	2177547.36	462098.27	4.24 (13.92)
12C	2177554.82	462102.07	4.26 (13.96)

4 Summary

Data were originally obtained for the dolos-armored Manasquan Inlet jetties during a monitoring effort conducted over the time period 1982-1984 under the MCNP Program. Armor unit breakage was documented, and quantitative data regarding armor unit movement were obtained. By means of limited ground-based surveys, aerial photography, and photogrammetric analysis, very precise base-level conditions were established for the dolos-armored jetties at Manasquan Inlet. Similar data were obtained and analyzed for the period 1984-1994 under the Periodic Inspections work unit of the MCNP Program.

The current monitoring (1998), also obtained under the Periodic Inspections work unit of the MCNP Program, entailed reestablishing targets and conducting limited ground-based surveys, aerial photography, and photogrammetric analysis for comparison with data obtained in 1994. The entire above-water armor unit fields were analyzed and armor unit movement quantified. A broken armor unit survey also was conducted during this effort. During the current monitoring, detailed analyses regarding horizontal and vertical displacements were conducted not only for the targets established on the dolosse but for the entire armor unit. Comparisons were made for the 1994 and current (1998) surveys. Also, using photogrammetric techniques, additional (nontargeted) dolosse were selected for analysis of armor unit movement between the 1994 and 1998 surveys. In addition, base data were obtained documenting the positions of the recently installed CORE-LOC armor units placed on the jetty heads in late 1997.

Results of the current monitoring effort indicate that dolosse movement was less dynamic during the period 1994-1998 as opposed to other survey periods. Maximum horizontal movement detected was 0.7 m (2.3 ft), and maximum vertical displacement was 0.3 m (1.2 ft). In general, however, most movements in both the horizontal and vertical directions have been less than 0.061 m (0.2 ft). Even though major storms occurred during the period, the dolosse appear to have settled into the structure and are more stable.

Horizontal movement for the majority of the dolosse was relatively uniform. The entire unit tended to move in the same direction as opposed to rotating. Of the units that rotated, however, the majority of units on the north jetty moved in a clockwise direction, while those on the south jetty rotated in a counterclockwise direction.

Evaluation of the vertical motions of the dolosse armor units revealed that some units moved upward slightly and some units slightly subsided. Average movements of the armor units were on the order of about 0.061 m (0.2 ft).

Eight broken units, four on each structure, were documented during the 1998 survey. Two of these were newly broken since the 1994 survey. One had a chipped fluke, probably because of impact, and the other had a broken shank, but was held together by reinforcing steel. A total of 17 broken units was observed during the 1994 survey, but many were removed during the 1997 CORE-LOC rehabilitation.

Detailed position data obtained for the CORE-LOC armor units during the current survey will establish a base from which to evaluate the movement of these innovative armor units in the future.

In general, methodology has been developed to assess the long-term response of the jetties to their environment at Manasquan Inlet. Comparison of armor unit data in future years will be conducted under the Periodic Inspections work unit to gather data by which assessments can be made. Insight gathered from these efforts will allow definite decisions to be made based on sound data as to whether or not closer surveillance and/or repair of the structure might be required to reduce its chances of failing catastrophically. Also, the periodic inspection methods developed and validated for these structures may be used to gain insight into other Corps' structures.

The methodology used to determine concrete armor unit movement for the Manasquan Inlet jetties was developed in 1984. It included monitoring the movement of concrete armor units based upon a fixed target and sketching the unit's position from the stereo model for current versus past periods. The scope of the work presented herein was essentially the same as conducted previously to achieve direct comparisons. Subsequently, however, procedures have changed for armor unit position analysis at other projects. Currently three targets are established, and the centroid of the armor unit is calculated. Not only target data but also the armor unit's centroid is tracked through time. The position of the axis of the armor unit relative to the vertical and horizontal planes is also included in the analysis. The use of this methodology for future monitoring of the armor units on the Manasquan Inlet jetties may be considered, time and funding permitting.

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13. ABSTRACT *(Maximum 200 words)*

Under the Periodic Inspections work unit of the monitoring Completed Navigation Projects Program, precise locations of dolos armor units on the Manasquan Inlet, New Jersey, jetty heads were reestablished and compared with data obtained previously. The vertical and horizontal positions of the dolosse were defined through limited ground surveys, low-altitude aerial photography, and photogrammetric analysis. Areas at the seaward heads of the structures were recently rehabilitated with CORE-LOC armor units. Base data were obtained relative to the precise vertical and horizontal positions of the CORE-LOCs. A broken armor unit survey also was completed. The site will be revisited periodically in the future, and the long-term response of the breakwater to its environment will be tracked. These periodic data sets will be used to improve knowledge in the design, construction, and maintenance of the existing structure as well as future coastal projects.

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